SCIENCE LECTURES FOR THE PEOPLE.

SCIENCE LECTURES

DELIVERED IN MANCHESTER,

1873 AND 1874.

FIFTH AND SIXTH SERIES.

MANCHESTER:
JOHN HEYWOOD, 141 & 143, DEANSGATE.
LONDON: SIMPKIN, MARSHALL, & CO.; F. WARNE & CO.

PREFACE TO THE FIFTH SERIES.

About 5,500 persons attended the eight lectures which have been delivered this season, and the audiences exhibited the same interest and attention as they showed on former occasions.

It is to be understood that each lecturer is entirely responsible for the statements as they appear in print.

Again we all have to thank those who have by their kind contributions rendered a continuation of the lectures possible; and I have to acknowledge the services of our treasurer, Mr. Thos. Harrison, and to express my regret at his retirement.

H. E. ROSCOE.

January, 1874.

PREFACE TO THE SIXTH SERIES.

THE attendance at the opening lecture, held in the Free Trade Hall, was about 3,700, whilst at each of the subsequent lectures it has averaged 675.

We are indebted to all the Lecturers of the season, and to Professor Tyndall and Sir John Lubbock in addition, for their contribution to our funds.

The following is a list of the Lectures which have been delivered:—

CRYSTALLINE AND MOLECULAR FORCES. By Professor Tyndall, F.R.S. (President of the British Association).

JOHN DALTON. By Professor Roscoe, F.R.S.

ON THE TRANSIT OF VENUS. By Dr. Wm. Huggins, L.L.D., F.R.S.

JOSEPH PRIESTLEY: HIS LIFE AND CHEMICAL WORK. By Professor Thorpe, F.R.S E.

GEOGRAPHICAL DISTRIBUTION OF MAMMALS. By P. L. Sclater, Esq., M.A., F.R.S. (Secretary to the Zoological Society).

EARTHQUAKES AND VOLCANOES. By Professor W. C. Williamson, F.R.S.

MODERN SAVAGES. By Sir John Lubbock, Bart., F.R.S., M.P.

PALESTINE EXPLORATION. By Major C. W. Wilson, R.E.

E. H. ROSCOE.

January, 1875.

GENERAL INDEX.

FIFTH SERIES.

SIXTH SERIES.

POLARISATION OF LIGHT.

A LECTURE, Delivered in the Hulme Town Hall, Manchester, on Tuesday, October 28th, 1873,

BY WM. SPOTTISWOODE, ESQ., F.R.S.

LIGHT is said to be polarised when it presents certain peculiarities, hereafter to be described, which it is not generally found to possess. These peculiarities, although very varied in their manifestations, have one feature in common, viz., that they cannot be detected by the unassisted eye, consequently special instrumental means are required for their investigation.

Now there are various processes, some occurring in the ordinary course of natural phenomena, others due to instrumental appliances, whereby a ray of light may be brought into the condition in question, or "polarised;" and it is a fact, both curious in itself and important in its applications, that any one of these processes (not necessarily the same as that used for polarising) may be used also as a means of examining whether the ray be in that condition or not. This latter process is called "analysation." When two instruments, whether of the same or of different kinds, are used, they are called respectively the "polariser" and the "analyser," and the two together are included under the general name of "polariscope."

It is considered as established that light is due to the vibrations of an elastic medium, which, in the absence of any better name, is called ether. The ether is understood to pervade all space and all matter, although its motions are affected in different ways by the molecules of the various media which it

permeates. The vibrations producing the sensation of light take place in planes perpendicular to the direction of the ray. The paths or orbits of the various vibrating ethereal molecules may be of any form consistent with the mechanical constitution of the ether, but on the suppositions usually made the only forms possible are the straight line, the circle, and the ellipse. But in ordinary light the orbits at different points of the ray are not all similarly situated.

This being assumed, the process of polarisation is understood to be the bringing of all the orbits throughout the entire ray into similar positions. And in the case where the orbits are all straight lines, they all lie in one and the same plane. For this reason the polarisation produced by most processes is called rectilinear, or, more commonly, plane polarisation.

The most simple, or ready to hand, method of polarising light is by reflection. Nearly all polished substances, except metals, have the property of producing this result. If light be reflected from the surface of a plate of glass, for instance, and then be received so as to be reflected from a second plate placed parallel to the first, no particular effect will be seen. But if the second plate be then turned round in such a way as always to preserve the same inclination to the ray reflected from the first, then the light reflected from the second plate will be found gradually to fade until the angle of turning has amounted to a right angle. If the turning be continued still further the light will gradually become brighter again, until when the angle of turning has reached a second right angle (or 180° in all) the light will have resumed its original brightness. This gradual fading and revival of the light, when the second plate is turned round in the manner above described, takes place in a greater or less degree when the rays fall upon the first plate at almost any angle. But, if that angle be varied, it will be found that the difference in the intensity of the light produced by turning the second plate is much increased between the ray and the plate until the angle reaches $35\frac{1}{2}°$, or thereabouts. When the ray falls at this angle the light is entirely extinguished by turning the second plate through a right angle. The light, therefore, in being reflected at this particular angle, has acquired the property of being extinguished by a second reflection, and this property forms one of the main features of polarisation. At first sight this may appear more curious than important, but the consequences of it will be more fully seen hereafter.

The effects here described may be produced by other polished substances; but amongst them there is, perhaps, none more

effective than mahogany. If the light reflected from a piece of mahogany furniture be examined or analysed by a second piece of such wood, in the way described for glass, it will be found to present similiar properties; but the angle of incidence at which the greatest effect of extinction is produced is not exactly the same for all substances.

In accordance with what was said at the outset, we may, if we please, cause the light to be reflected from one substance, and examine it by reflecting it from another. For example, we may analyse by a plate of glass the light reflected from a lake, or the sea, or from a basin of water, &c., and the same effect of fading and revival will be noticed.

If the plate used for analysing be transparent, as in the case of glass, part of the light will be reflected as mentioned above; but part also will pass through, or, as it is termed, will be transmitted. And if, when the arrangements are made as before, the second plate be turned round, it will be found that the transmitted light has acquired the same property as the reflected, but with this difference, that the position of the second plate, which makes the reflected ray the feeblest, or extinguishes it, makes the transmitted ray the brightest; and that which makes the reflected the brightest, makes the transmitted ray the feeblest. In this experiment it will be found difficult actually to extinguish the transmitted rays; but if we use several plates of glass forming a little pile or bundle, instead of a single plate, we shall find the effect much stronger. And if the glass be very thin and clear, so that five or six can be used, we shall be able on turning the bundle round entirely to extinguish the transmitted ray. By putting together in this way a few pieces of glass, say 1½ inch in length, and one inch in breadth, and by looking through the bundle obliquely at an angle of about one-third of a right angle, we shall be able to produce not only the effects above-mentioned, but also those described below as produced by the more complete polarising apparatus. The experimenter will, however, perhaps not be disappointed if the effects are not so vivid as those shown to-night.

We next come to the subject of polarisation by double refraction. There are a large number of crystals which have the property of generally dividing every ray which passes through them into two. But the extent of separation of the two rays varies with the direction of the incident ray in reference to the natural figure of the crystal. In every double refracting crystal there is at least one, and in many there are two, directions in

which no such separation takes place. These directions are called optic axes.

Of such crystals Iceland spar is the most notable instance. If we take a block of such spar split into its natural shape—a rhombohedron—and for convenience cut off the blunt angles by planes perpendicular to the line joining them, it will be seen that a ray of light transmitted perpendicularly to these planes—that is, parallel to the line joining the blunt angles—is not divided. If, however, the crystal be tilted out of this position, in any direction, it will be seen by the appearance of two images instead of one that the rays are divided into two.

Let us now take a sphere of Iceland spar, which will act upon the rays issuing from the lamp as a powerful lens. In every position in which it is placed it produces two images on the screen; but in that in which I now place it the two images are concentric, differing only in this, that one is larger than the other.

This difference in the size of the images shows, moreover, a very important property of double refracting crystals. The amount of refraction produced by a transparent medium standing in air depends, as is well known, upon the velocity with which a ray of light traverses the medium compared with that with which it traverses air. The smaller the velocity in the medium, the greater the refraction. The greater the refraction, the greater the magnifying power of a lens constructed of that medium. Hence, in the two concentric images we can at once point to the system of rays which has traversed the crystal at a lower velocity than the other.

If the nature of the light in the two images thus formed be examined or analysed by any polarising instrument, such as a reflecting plate, or by a bundle of glass plates described above, it will be found to possess the property of being extinguished by turning the instrument used for analysing; in other words, it will be found to be polarised in both cases: but, inasmuch as the two images are alternately extinguished, as in the case of the rays reflected and transmitted by the pile of glass plates, we may conclude that the light in the one image has had its vibrations arranged at right angles to those of the other.

On these principles polarising and analysing instruments have been constructed by various combinations of wedges or prisms of Iceland spar, the details of which it is not necessary to describe in full. But the general problem and object proposed, in all of them, has been to cause such a separation of rays that one set may be further diverted, and afterwards thrown altogether out of

the field of view. This done, we have a single beam of completely polarised light, and a single image produced from it. One such instrument, the Nicol's prism, on account of its great utility, is in very extensive use.

Two such instruments, when used together, are respectively called the "polariser" and the "analyser," on account of the purposes to which they are put. These when placed in the path of a beam of light give rise to the following phenomena, which are, in fact, merely a reproduction in a simplified form of what has gone before.

When polariser and analyser are placed in front of one another in what may be called a similar position, that is, when the vibrations in the image transmitted by the one are parallel to those in the image transmitted by the other, the light will be projected on the screen exactly as if only one instrument existed. If, however, one instrument, say the analyser, be turned round, the light will be seen to fade in the same way as in the case of the glass plates; until, when it has been turned through a right angle, or, as it is usually expressed, when the polariser and analyser are crossed, the light is totally extinguished.

We now proceed to the consideration of the colours produced by plates of crystal when submitted to the action of polarised light. A crystal very commonly used for this purpose is selenite or sulphate of lime, which is readily split and ground into flat plates of almost any required thickness. If such a plate be placed between the polariser and analyser when crossed it will be found that there are two positions at right angles to each other, in which, if the selenite be placed, the field will remain dark as before. The selenite is, in fact, a doubly-refracting crystal, and the positions in question are those in which the plane of vibration of one ray coincides with that of the polariser (or analyser), and that of the second ray with that of the analyser (or polariser). In every other position of the selenite, and notably when it has turned through 45° from either of the positions before mentioned, or neutral positions, as they may be called, light passes through, and the field becomes bright. If the thickness of the selenite be considerable the field when bright will be colourless; but if it be inconsiderable the field will be brilliantly coloured with tints depending upon the thickness of the plate.

Supposing, however, that, the selenite remaining fixed, the analyser be turned round, we shall find that in the first place the colour gradually fades as before, until when the analyser has been

turned through $45°$ all trace of colour is lost. After this, colour again begins to appear—not, however, the original tint, but its complementary. A general explanation of this change of colour is already furnished by our former experiments. Doubly-refracting crystals generally, in the same way as Iceland spar, divide every ray, and consequently every beam of light which passes through them, into two, so that of every object seen through them, or projected through it on to a screen, two images are produced. These two, being parts of one and the same beam of light, would, if recombined, reproduce the original beam, and the same is, of course, the case with the two images.

But in order to explain how it comes to pass that colour is produced at all, we must have recourse to some considerations based upon the Wave Theory of Light. And, first, as to the mode in which waves may be produced.

Consider a row of balls lying originally in a horizontal straight line. Let the balls start one after another and vibrate at a uniform rate up and down. At each moment some will be at a higher, others at a lower level, at regular intervals, in a wave-like arrangement; the higher forming the crests, the lower the hollows of the waves. The distance from crest to crest, or from hollow to hollow, is called the *wave length.* The distance from crest to hollow will consequently be half a wave length. This length will be uniform so long as the vibrations are executed at a uniform rate.

Each ball in turn will reach its highest point and form a crest; so that the crests will appear to advance from each ball to the next. In other words, the waves will advance horizontally, while the balls vibrate vertically.

If the row of balls were originally arranged in a wave form, and caused to vibrate in the same way as before, those on the crests would vibrate wholly above, and those in the hollows wholly below, the middle line. The remainder would vibrate partly above and partly below that line. When the balls originally on the crests rise to their highest points, those in the hollows will fall to their lowest positions, and the height of the wave will consequently be doubled. When the balls originally at the crests fall, those in the hollows will rise, both to the middle line; and the wave will consequently be annihilated. The first of these cases corresponds to a condition of things wherein the crests of the new wave-motion coincide with those of the old, and the hollows with the hollows; the second, to that wherein the crests of the new coincide with the hollows of the old, and *vice versâ.*

Hence, when two sets of waves are coincident, the height of the wave, or extent of vibration, is doubled; when one set is in advance of the other by half a wave length, the motion is annihilated. The latter phenomenon is called *interference.* When one set of waves is in advance of the other by any other fraction of a wave length, the height of the wave, or extent of vibration, is diminished, but not wholly destroyed; in other words, partial interference takes place.

The Wave Theory of Light consists in explaining optical phenomena by vibrations and waves of the kind above described. And according to that theory the direction in which the waves move is the direction of propagation of the ray of light.

The intensity of light depends upon the extent of the vibrations, or the height of the waves; the colour, upon the number of vibrations executed in a given interval of time. And since throughout any uniform medium the connection of the parts and the rate of propagation may be considered to be uniform, it follows that the waves due to the slower vibrations must be longer than those due to the more rapid. Hence the colour of the light may be regarded as depending upon the wave length.

In the illustrations of wave motions given above, the balls would represent successive portions or molecules of the ether; and the means whereby the motion of one molecule is transmitted to its neighbour is the elastic cohesion attributed to the whole medium in the hypothesis above mentioned.

In plane polarised light, such as is produced by tourmalin plates, by double refraction in Iceland spar, &c., the vibrations are rectilinear, and are executed in one and the same plane throughout the entire length of the ray. In circularly-polarised light the vibrations are all circular, and the motion is performed in the same direction.

These general considerations being premised, we are in a position to trace the course and condition of a ray of light issuing from the lamp or other source, and traversing first the polarising Nicol's prism; secondly, the plate of doubly-refracting crystal; thirdly, the analysing Nicol.

The vibrations of the ray on leaving the polariser are all restricted to a single plane. On entering the plate of a doubly-refracting crystal, every ray is divided into two, whose vibrations take place in planes perpendicular to one another. The angular position of these planes about the axis of the beam of light is dependent upon the angular position of the crystal plate about its centre. The two sets of rays traverse the crystal with different

velocities, and therefore emerge with a difference of phase. The amount of this difference is proportional to the thickness of the plate. On entering the analyser the vibrations of each pair of rays are resolved into one plane; and are then in a condition to exhibit the phenomena of interference. If the plane of vibration of the analyser be parallel to one of those of the plate, that ray will be transmitted without change: the other will be suppressed. In any other position of the analyser those rays of any particular colour whose difference of phase most nearly approaches to half a wave length, will be most nearly suppressed; and those in which it approaches most nearly to a whole wave length will be most completely transmitted. The amount of light suppressed increases very rapidly in the neighbourhood of the ray whose difference of phase is exactly a half-wave length; so that with plates of moderate thickness a single colour only may in general terms be considered to be suppressed. This being so, the beam emergent from the analyser will be deprived of that colour, and will, in fact, consist of an assemblage of all others; or, in other words, will be of a tint complementary to that which has been extinguished.

It has been remarked that the colour produced by a plate of selenite depends upon the thickness of the plate. In fact, the distance whereby one ray falls behind the other in traversing the plate increases with the thickness, and consequently if, for a given thickness, it amounts to a half-wave length of the shortest (say violet) waves, for a greater thickness it will amount to a half of a longer (say green) wave, and so on. And if, instead of a series of plates of different thicknesses, we use a wedge-shaped plate, the entire series of phenomena due to gradually-increasing retardation will be produced. This is easily seen to consist of a series of tints due to the successive extinction of each of the rays, commencing with the violet, and ending with the red; and the tints will consequently have for prevailing hues the colours of the spectrum in the reverse order. This series of colours will be followed by an almost colourless interval, for which the retardation is intermediate between a half red-wave length and three half violet-wave lengths. Beyond this again the series of colours will recur, and the same succession is repeated as the wedge increases in thickness. It will, however, be observed that the colours appear fainter each time that they recur, so that when the thickness reaches a certain amount (dependent upon the nature and retarding power of the crystal) all trace of colour is lost.

By making use of the principle that the colour produced

depends upon the thickness of the plate, selenites have been cut of suitable shapes and thicknesses, so as to produce coloured images of stars, flowers, butterflies, and other objects.

The phenomena exhibited by selenite are also produced by other crystals; but the facility with which plates of the former substance can be obtained, causes them to be generally used in preference to others. There is, however, a peculiar class of crystals, of which quartz, or rock crystal, is the most notable, which gives rise to effects different from those hitherto described.

Each of the images will exhibit a gradual change of colour while the analyser is being turned; and the tints will be, as explained before, complementary to those which are successively extinguished. But it should be here explained that there are two kinds of quartz, one called right-handed and the other left; and that, for a given direction of rotation of the analyser, these cause the colours to follow one another in opposite orders. A similar effect is produced by turning the polariser round in the opposite direction.

If the plate be composed of two parts, one of right-handed, the other of left-handed quartz, placed side by side, any change in the plane of polarisation will affect the two parts in opposite ways. In one part the colours will change from red to violet; in the other from violet to red. At two positions of the polariser, or analyser, the colours must be identical. With plates, as usually cut, one of these identities will be in the yellow, the other at the abrupt passage from violet to red, or *vice versâ*. In this case the field appears of a neutral tint, and the slightest change in the plane of polarisation exhibits a marked distinction of colour, one part verging rapidly to red, the other to violet. This arrangement is called a biquartz, and affords a very delicate test for determining the position, or change of position, of the plane of polarisation, especially in cases where feebleness of light or other circumstances interfere with the employment of prismatic analysis.

The phenomena hitherto described manifestly depend upon the internal structure of the crystal plate, in virtue of which it affects the vibratory movement of the ether within it differently in different directions. And seeing that most crystals, when broken, divide themselves naturally into smaller crystals having the same form, *i.e.*, having their planes and edges similarly inclined, we are naturally led to conclude that the structure of these bodies may differ not so much in different parts, as along different lines or planes connected with the forms into which they break, or (as it is also described) with their planes of natural cleavage. And this

suggests the question whether an uncrystalline body might not, by pressure, or strain, or other mechanical distortion, be caused to affect the motions of the ether within it in a manner dependent upon their direction, and in that way to exhibit chromatic effects with polarised light, analogous to those described above. Experiment answers this question in the affirmative.

The simplest experiment in this branch of inquiry consists in taking a rectangular bar of ordinary glass; and, having crossed the polariser and analyser so as to give a dark field, to strain the bar with both hands as if we were trying to bend it or break it across. The side towards which it may be supposed to be bent is, of course, compressed, while the opposite is stretched out. Between these two there must be an intermediate band, more or less midway between the two, which is neither compressed nor stretched. The moment the strain is put upon the bar light will be seen to pass through the parts of the bar nearest to both sides, while a band remains dark midway between the two.

This shows that the mechanical strain has imparted to portions of the glass a structural character analogous, at all events optically, to that of a crystal. The effects may be increased and rendered more striking by placing the glass in a frame furnished with a screw, by which the rod may be firmly held and considerable pressure applied at particular points. When this is done the structural character becomes more completely developed, and the dark band is fringed with colours which appear to flow inwards or outwards according as the pressure is increased or diminished. A slightly different, but more effective, exhibition of chromatic polarisation is produced by squeezing a thick square plate of glass in a vice. In this case the pressure may be carried further without fear of fracture, and the chromatic effects heightened.

It is, however, well known that molecular forces, such as those due to heat and cooling, in many cases far transcend in intensity those which we can exert by mechanical arrangements. And, in fact, if a block of glass be unequally heated to a very moderate degree, the internal structural effects immediately reveal themselves by dark bands, which indicate the border land between strain and pressure. As the block cools these landmarks gradually disappear, and the field becomes again uniformly dark. But by far the most splendid effects (and these are permanent) are produced by unannealed glass—that is, by glass which has been rapidly and therefore unequally cooled. When a mass of glass has been cast in a mould in the form of a thick plate, then, whatever be the

contour line, the outside will cool first and become a rigid framework, to which the interior of the mass must accommodate itself. The nature and direction of the pressure at each point of the interior will be primarily dependent upon the form of the contour; and by adopting various forms of contour the most beautiful and varied figures with coloured compartments may be produced. The forms and colours of the figures produced by transparent bodies when submitted to polarised light have been conversely used as a means of measuring, with almost unparalleled accuracy, the mechanical pressures which such a body is undergoing.

Besides glass, many other substances may be used as reflectors so as to produce polarisation; for example, leaves of trees (particularly ivy), mahogany furniture, windows, shutters, and often roofs of houses, oil-paintings, &c., and last, but not least, the surface of water. In each of these cases, when the reflected beam is examined with a Nicol the alternations of light and darkness are most strongly marked, and the colours (if a crystal plate be used) are most vivid, or, in technical language, the polarisation is most complete, when the light is reflected at a particular angle. In proportion as the inclination of the incident light deviates from this angle the colours become fainter, until, when it deviates very greatly, all trace of polarisation disappears.

It will be found very interesting to examine the polarisation of sunshine reflected from ripples on the surface of a lake—or, better still, from the waves of the sea—and its different degrees of completeness produced at the variously-inclined portions of the waves. But, without having recourse to nature on so large a scale, an artificial piece of water may be placed in our room. A tea-tray will serve as well as anything else to form our little sea; and a periodic tap at one corner will cause ripple enough for the present purpose. The waves appear bright, and, although brighter in some parts than others, they are nowhere entirely dark. But on turning the Nicol round the contrast of light and darkness becomes much stronger than before. In parts the light is absolutely extinguished, or the polarisation is complete; in others it is incomplete in various degrees. And if a selenite or other crystal plate be introduced, we have the beautiful phenomena of iris-coloured rings playing over the surface of our miniature sea; and, indeed, if we become practised in the use of an analysing apparatus of any kind we shall find that we are continually using polarised light, although we should otherwise have been unaware of the fact. To mention one more instance; if we turn our

attention to the sky, and on a clear bright day sweep the heavens with such an instrument, we shall find traces of a polarisation in many directions. But if we observe more closely we shall find that the most marked effects are produced in directions at right angles to a line drawn from one eye to the sun, when, in fact, we are looking across the direction of the solar beams. Thus, if the sun were just rising in the east, or setting in the west, the line of most vivid effect would lie on a circle traced over the heavens from north to south. If the sun were in the zenith, or immediately over-head, the most vivid effects would be found on the horizon: while at intermediate hours the circle of strongest polarisation would shift round at the same rate as the shadow on a dial, so as always to maintain its direction at right angles to a line joining ourselves and that of the sun.

On this principle Sir Charles Wheatstone constructed his Polar clock, one of the few practical applications which this branch of polarisation has yet found. The instrument has been thus described by the inventor:—

"At the extremity of a vertical pillar is fixed, within a brass ring, a glass disc, so inclined that its plane is perpendicular to the polar axis of the earth. On the lower half of this disc is a graduated semicircle divided into twelve parts (each of which is again subdivided into five or ten parts), and against the divisions the hours of the day are marked, commencing and terminating with VI. Within the fixed brass ring containing the glass dial plate, the broad end of a conical tube is so fitted that it freely moves round its own axis; this broad end is closed by another glass disc, in the centre of which is a small star or other figure, formed of thin films of selenite, exhibiting when examined with polarised light strongly-contrasted colours; and a hand is painted in such a position as to be a prolongation of one of the principal sections of the crystalline films. At the smaller end of the conical tube a Nicol's prism is fixed so that either of its diagonals shall be 45° from the principal section of the selenite films. The instrument being so fixed that the axis of the conical tube shall coincide with the polar axis of the earth, and the eye of the observer being placed to the Nicol's prism, it will be remarked that the selenite will in general be richly coloured; but as the tube is turned on its axis the colours will vary in intensity, and in two positions will entirely disappear. In one of these positions a small circular disc in the centre of the star will be a certain colour (red, for instance), while in the other position it will exhibit the complementary colour. This effect is obtained by

placing the principal section of the small central disc $22\frac{1}{2}°$ from that of the other films of selenite which form the star. The rule to ascertain the time by this instrument is as follows:—The tube must be turned round by the hand of the observer until the coloured star entirely disappears, while the disc in the centre remains red; the hand will then point accurately to the hour. The accuracy with which the solar time may be indicated by this means will depend on the exactness with which the plane of polarisation can be determined. One degree of change in the plane corresponds with four minutes of solar time.

"The advantages a polar clock possesses over a sun-dial are: (1) The polar clock being constantly directed to the same point of the sky, there is no locality in which it cannot be employed; whereas, in order that the indications of a sun-dial should be observed during the whole day, no obstacle must exist at any time between the dial and the places of the sun, and it therefore cannot be applied in any confined situation. The polar clock is, consequently, applicable in places where a sun-dial would be of no avail—on the north side of a mountain or of a lofty building, for instance. (2) It will continue to indicate the time after sunset and before sunrise—in fact, so long as any portion of the rays of the sun are reflected from the atmosphere. (3) It will also indicate the time, but with less accuracy, when the sky is overcast, if the clouds do not exceed a certain density.

Many other circumstances under which polarisation is to be discovered might be mentioned; and it is even difficult to realise how deeply seated this principle is in the processes of nature. But time warns me that I must bring this rapid and imperfect sketch of the subject to a close.

And if I might, in conclusion, wander for one moment from the region of facts to the region of imagination, I would suggest that, as our forefathers believed that they saw in the rainbow a sign set in the heavens that a new era had dawned upon the earth, and that it was a token that the waters of the deluge should never again so return as to cover the earth, so may we perhaps see in this not less beautiful exhibition of colour and of form produced by polarised light, as it were, a sign set and embodied in these crystals of ours that an era of intelligence has already dawned upon our land, and a token that the dark waters of ignorance shall never again so return as to overwhelm mankind.

Mr. Spottiswoode is about to publish, first in *Nature*, and afterwards in a separate volume of the "*Nature* Series," a much fuller account of the subject of "Polarised Light."

How Flowers are Fertilised.

A LECTURE, Delivered in the Memorial Hall, Manchester, on Wednesday, November 5th, 1873.

BY A W. BENNETT, ESQ., M.A., B.SC., F.L.S.

THE subject which is to engage our attention this evening may not seem at first sight one of such thrilling interest as some of those which have been opened to you by distinguished workers in other branches of science. We have not here to do with brilliant researches, which have revealed to the inhabitants of this globe something of the actual constitution of worlds separated from us by many millions of miles; nor have we to investigate the structure of this globe of ours thousands of years ago, and to trace the steps by which it has assumed its present form and appearance; or to endeavour to depict the form or habits of our earliest progenitors. We shall rather, as it were, have to pay a visit to Nature in her everyday dress, and to watch the mode in which she goes about one of her daily employments; and I shall be disappointed if you do not agree with me before we have finished, that it is thus only that we can truly examine Nature's workmanship; that we can recognise the wonderful fertility of her resources; the marvellous power of adaptation to every-varying circumstances; the constant striving after perfection; the beauty and the truth that surround us on every side.

We may regard a plant—and it is indifferent for our purpose whether we take the tiniest weed or the stateliest forest tree—from two points of view. We may consider only its own individual life, and the parts of the plant, or organs as they are termed, whose object is the maintenance of this life. With these organs, however—termed for the sake of distinction the vegetative or nutritive

organs, and comprising the root, the stem, and the leaves—we have at present no concern, interesting as is the study of the structure by which they are adapted to their end. The other point of view is not the individual life of the plant, but the means with which it is furnished for perpetuating the race—for raising up new individuals after it has itself run its allotted term of life. The parts which are specially contrived for the purpose of effecting this object are called the organs of reproduction, and are those included under the ordinary term, the flower of the plant. A flower is, therefore, a complex organ, or rather an assemblage of organs, all having for their final purpose a certain process—which it is our purpose to-night to study somewhat in detail—known as the process of fertilisation. But before doing so I must describe in botanical language the various parts or organs of which a flower consists.

If we look at an ordinary flower from the outside, the part which is first brought under our notice is a kind of cup, generally, but not always, green, which is called the *calyx*. Before the flower opens, when it is in the bud-condition, this cup envelopes the internal parts of the flower, which are then in the process of development, and protects them from injury by any external agency; and the main function or purpose of the calyx may therefore be considered to be one of protection. Within the calyx is the most conspicuous part of the flower, generally, but not always, brightly coloured, which is called the *corolla*. The main function of the corolla is, by means of two properties which it ordinarily possesses—colour and scent—to attract insects to the flower for a purpose which we shall understand presently. Within the corolla come a number of bodies generally differing altogether in shape and appearance both from the *sepals*, or parts of which the calyx consists, and the *petals*, or parts of which the corolla consists, and, ranging in number from one or two to a larger number than can be easily counted, the *stamens*. Now while the calyx and corolla are of subordinate importance, as we shall presently see, in the construction of the flower, the presence of one or more stamens is absolutely necessary to ensure the reproduction of the plant. Each stamen consists of two parts, the *filament* or stalk, and the *anther;* the latter only being the really essential part of the stamen. The anther is a bag containing a quantity of very fine dust known as *pollen*, one of the two bodies which unite to bring about the process of fertilisation. Lastly, within the stamens, occupying always the centre of the flower, is the last of the reproductive organs of which it is composed, the

pistil, which again assumes very different forms in different flowers. The pistil consists, in its most perfect form, of three parts: the bottom part is in the form of a bag or hollow receptacle, and is called the *ovary*, because it contains a number of minute egg-shaped bodies, the *ovules*; rising from the apex of the ovary is a stalk-like part, the *style*, surmounted at its summit by a body of very peculiar structure called the *stigma*, the purpose of which we shall have to examine presently. When the flower withers, the greater number of the parts which we have now been describing disappear, especially the corolla, the stamens, the style, and the stigma, and nothing is left except the ovary, sometimes surrounded by the persistent calyx. The ovary now grows and developes into what is commonly called, when mature, the *seed-vessel*, or more often in botanical terminology, the *fruit*; and the seed-vessel or fruit contains the *seeds*, which are the mature or ripened ovules, just as the seed-vessel is the mature or ripened ovary. But the change from ovule into seed is not one of growth merely, but is dependent on the formation within the ovule of a body called the embryo; and this embryo can only be produced by the operation of the perfectly definite process which we have now to examine in detail —the process of the fertilisation of the ovule.

If an ovule, at the time when the plant is in flower, is examined minutely under the microscope, it is found to consist almost entirely of cellular tissue, *i.e.*, of a number of minute sacs called cells, placed side by side in close juxtaposition, which form the *nucleus* of the ovule. These are usually enveloped in two coatings of firmer texture, an inner and an outer one, called the *secundine* and the *primine*. These two coatings are, however, not continuous over the apex of the ovule, where they leave an open channel called the *foramen* or *micropyle**, communicating with the nucleus, and with a large cavity within it which is known as the *embryonic sac*. In by far the majority of plants the ovule does not, however, retain the position here indicated, but becomes inverted in the course of its growth, one side growing more rapidly than the other, so as to bring the opening or micropyle into close proximity to the *placenta*, as the point of attachment between the ovule and the wall of the ovary is called.

If we now examine closely under the microscope one of the grains of the pollen contained in an anther, we shall find that it also has a somewhat complicated structure. Outwardly these grains vary greatly, both in form, colour, and size. Generally

* A Greek term, meaning a "little gate."

spherical, they are sometimes oval; or triangular as in the Fuchsia, or Evening Primrose; or covered with minute spines, as in the Hollyhock, or Aster. They also are found to be hollow bodies, containing an oily fluid in the inside, protected by two coats, an inner and an outer one, called in this case the *intine* and the *extine*. At one or more points of its surface the extine is weaker, and allows the intine to be seen through it.

When the anther is ripe and discharges the pollen, a certain portion of it falls on the pistil, and on that portion of it at the summit of the style which we have called the stigma. The stigma is always distinguished by producing on its surface, at some period or other, a sticky glutinous fluid, which causes the pollen-grains to adhere to it. This is not the only effect on the pollen-grains of the viscid secretion of the stigma; it excites, by some unknown power, the development of the intine, or inner coating of the pollen-grain, which bursts through the extine, or outer coating, at the weak places I have already described, and protrudes in the form of a tube. This tube, called the *pollen-tube*, penetrates the loose cellular tissue of the style, grows with astonishing rapidity, and sometimes to an extraordinary length (in the common spring Crocus the style is sometimes several inches in length), through the wall of the ovary, the cavity of which it finally enters. The end of the pollen-tube now, so to speak, seeks out an ovule. From the position of the ovule being, as I have described it, usually inverted, the opening, or micropyle, is not far from the wall of the ovary. This micropyle the pollen tube enters, passing through the cellular tissue of the nucleus, enters the large cavity which I have described as the embryonic sac; there finally its end gives way, and the contents of the pollen grain are discharged into the embryonic sac.

This is a brief summary of the process known as the fertilisation of the ovule, without which it is impossible for fertile seeds to be produced. Its immediate consequence is the formation within the embryonic sac of a body called the *embryo*, which at once begins to grow rapidly at the expense of the tissue of the nucleus, the whole of which it frequently absorbs. It is the presence of this embryo that constitutes the difference between the unfertilised ovule and the fertilised seed, and on it depends the power of the seed to germinate and to produce new individuals like unto itself.

But the mode in which the contact between the pollen-grain and the stigma is carried out by Nature is not quite so simple as would be inferred from the description I have hitherto given.

I have at present spoken of flowers as if they always contained both a pistil and one or more stamens. And in the greater number of flowers with which we are familiar this is the case, but not in all. In the Melon, for instance, the Cucumber, and other plants belonging to that tribe, some of the flowers are "male," *i.e.*, possess stamens, but no pistil; while others are "female," *i.e.*, possess a pistil, but no stamens. Each flower is, as it were, the complement of the other. In these cases it is obvious that the pollen necessary for the fertilisation of the ovule must be conveyed by some foreign agency from the male to the female flowers, which are in this case borne on different plants. The gardener generally does this artificially; but we shall see presently that Nature herself supplies a means. This fact in natural history was known as long ago as the time of Herodotus, who describes the process of "caprification," *i.e.*, the transference of the pollen, by which a crop of dates was ensured on the Egyptian palm-trees, from the male to the female trees. Another instance of this is in the case of the *Aucuba japonica*, or, as it is commonly called, the "variegated laurel," of our gardens and shrubberies. This plant was introduced into this country many years ago from Japan, by the Dutch. The *Aucuba* is also one of these *diœcious** plants, as botanists term them, in which the same individual bears only male or only female flowers, and the plant first introduced happened to be a female one. Since it did not bear seeds, the only method of propagation was by cuttings; and till within the last few years the whole of the innumerable *Aucubas* throughout the country had been obtained in this way, or, in other words, were but separated parts of the original individual. Plants reproduced in this way can only repeat the characters of the parent plant; every spring, therefore (about March), we might see our "variegated laurels" bearing their small purplish female flowers, but never by any chance producing seed. Not many years ago, however, male plants were also introduced by Mr. Fortune; the female flowers were fertilised, and bore seed, which being sown produced new plants, some female and some male. The pollen of the *Aucuba* is now an article of trade in Covent Garden market, and we may frequently see the shrubs ornamented with their bright red berries. Another instance of an unisexual but not a diœcious plant—for, in this case, the male and female flowers are borne on the same plants—is furnished by the common Hazel, on which, moreover, the two

* From two Greek words, meaning "two houses."

kinds of flowers are so different that if you saw them apart you would hardly believe that they had anything whatever to do with one another. The male flowers are, in this instance, the familiar yellow catkins which come out soon after Christmas, and remain on the tree for a few weeks, when they drop. Each catkin contains a very large number (perhaps 100 to 120) of such flowers; each male flower consists of 10 to 12 anthers, and each anther contains an innumerable number of very fine light powdery pollen-grains. The female flowers are seen on the same branches in the form of minute bright threads, which are, in fact, the stigmas, the ovaries being concealed beneath a number of scales at the base. Some of the pollen-grains fall on the stigma from the catkin, push out their pollen-tubes, and fertilise the ovule in the ovary, which then developes into the nut.

But one of the most beautiful examples of the mode of fertilisation in these unisexual plants is seen in a little water plant, the *Vallisneria spiralis*, a native of the south of Europe, grown very commonly in fresh-water aquariums, and affording a very beautiful object under the microscope, to illustrate the continuous circulation or rotation of the contents of the cells of which the leaves are composed. The *Vallisneria* is, like the *Aucuba*, diœcious, The flowers of the male plants are borne on very short stalks, which do not raise them to near the surface of the water. The female flowers, on the other hand, are supported on the ends of very long stalks, which are curved into a corkscrew-like spiral, and are elastic. Submerged when in a young state completely beneath the water, when the pistil is in a condition for fertilisation, the spiral coil relaxes so as to bring the flower to the surface. About the same time the male flowers break off from their short stalks and rise to the surface; they move about for a time as if seeking the female flowers, at the same time discharging their pollen, some of which reaches the stigmas and fertilises the ovules. After the fertilisation is effected the coil of the stalk of the female flowers again contracts so as to bring the flower beneath the water, where the seeds are matured. This illustration introduces us incidentally to one of the most curious chapters in the more scientific departments of botany, that of the spontaneous or quasi-spontaneous movements of plants.

It will be seen from these examples that some means are necessary, in the case of those plants where the stamens and pistils are in different flowers, or even on different individuals for the conveyance of the pollen from the one to the other. It might be supposed, on the contrary, that in perfect or "hermaphrodite"

flowers, in which both kinds of organs are present, the process would be a much simpler one, and that the pollen has nothing to do but to fall out of the anther on to the stigma in order to effect fertilisation. It was pointed out, however, as long ago as the close of last century, by one of those keen observers of Nature with whom that period abounded, Karl Conrad Sprengel, that the structure of a large number of flowers was such as to render this simple arrangement impossible. But the fact appeared to have been altogether lost sight of until attention has again been called to it, within the last few years, by a number of naturalists, among whom may be mentioned especially Hildebrand and Hermann Müller, in Germany; Delpino, in Italy; and, above all, Darwin, in this country, who has reduced the observed facts to a scientific law. A number of experiments, conducted with a patience and a philosophical power of observation which cannot be too highly praised, led Darwin to the conclusion that when a flower is "self-fertilised"—*i.e.*, when the ovules are fertilised by pollen from a stamen belonging to the same flower—the number of seeds produced is smaller, or their vigour is less, than if it is "cross-fertilised"—*i.e.*, impregnated by the pollen conveyed from a stamen belonging to some other flower of the same species; and that if this process of self-fertilisation is continued through several generations, the plant at length becomes altogether sterile. This fact, when fully established experimentally, Darwin crystallised into the aphorism now so often quoted, that "Nature abhors perpetual self-fertilisation." Now for the facts: they are patent even to the most careless observer. In unisexual flowers it is obvious that cross-fertilisation must always take place, and even in hermaphrodite flowers we shall find that the same rule must necessarily prevail in most cases.

If we take any flower belonging to the genus *Campanula*, as the Harebell, the Canterbury Bell of the gardens, or large wild Bell Flower of our hedges, and examine the structure of the flower when it is fully open, we shall see that the end of the style is divided into three conspicuous white stigmas covered with little papillæ, which indicate that they are in a "receptive" condition, *i.e.*, a state in which they are able to excite the protrusion of the pollen-tubes from the pollen-grains. When we look for the stamens, however, we shall find that the anthers have completely withered up, the pollen having been, in fact, discharged from them almost before the flower expanded—at all events, long before the stigmas had opened and exposed their papillæ. It is, therefore, almost impossible that any of the pollen can have fallen on

the stigmas; and, if further examination is made, the pollen will be found collected in enormous glutinous masses on the hairs which clothe the lower part of the style. What then becomes of it we shall see presently. The same phenomenon is exhibited by the Pink, the Sweet William, the Stitchwort, or any other plant belonging to the natural order *Caryophyllaceæ*. Before the stigmas in plants of this order—sometimes three, sometimes five—are expanded, the anthers, which hang loosely suspended at the end of the filaments, have dropped off them and completely disappeared. Exactly the reverse is the case in a common roadside weed, the Rib-grass, or *Plantago lanceolata*. Here the flowers grow in a dense spike; in those which are just opening the stigma will be seen protruding like a fine feather from the calyx and corolla, but there will be no appearance of stamens. Examine the same flower at a later period, and you will find the stigma entirely disappeared; and then the stamens are protruded from the calyx and corolla, delicately poised, like in the Pink, at the end of long slender filaments. In a large number of flowers, indeed, the structure of the flower is such as to indicate that the parts are specially contrived so as to exclude the possibility of self-fertilisation. This is very well illustrated in the case of a beautiful flower common in the Lancashire bogs, and in the mountain districts of Cumberland and Westmoreland—the Grass of Parnassus, or *Parnassia palustris*. Five stamens, in this instance, surround the conical pistil, and are mature considerably before the stigmas are developed. The stamens are developed in succession one after another. As each ripens its filament lengthens, and it places itself right on the top of the stigma with its back to it, and the pollen is then discharged from the anther on the side away from the stigma, so that it is scarcely possible for any to fall on it; and this is done by each of the five stamens in succession. In the Allspice Tree, or *Calycanthus*, a scented tree, flowering in the winter, we have a very similar contrivance for preventing the pollen from falling on the stigma of its own flower.

It is obvious, therefore, that if the pollen is not intended, as a rule, to fertilise the ovules in its own flower, some arrangement must be necessary for carrying it from flower to flower; and these are the arrangements for effecting cross-fertilisation, about which so much has been written of late in botanical works and in popular treatises. The arrangements for this purpose may be classed under two heads—those dependent on the wind, and those dependent on the visits of insects.

In the Hazel, the structure of the flowers of which has already been described, we have a very good instance of fertilisation by the agency of the wind. Everything here favours the dissemination of the pollen by the least breath of air. The catkins are lightly hung, so as to be swayed by every passing breeze; the pollen consists of very light dust-like grains, and the quantity of it is prodigious. The flowers also appear before the leaves are expanded, so that there is nothing to prevent the pollen being carried in all directions, and some must almost inevitably fall on the female flowers. If, indeed, the red stigmas are examined under a pocket lens, some of the fine grains will almost certainly be found adhering to them. In the Rib-grass, or *Plantago*, again, where we have seen that the anthers are suspended at the end of long slender filaments, the fertilisation is effected in the same manner. These two instances illustrate the law that those flowers in which the wind is the agent for their fertilisation are in general small and inconspicuous, there being no object for their being brightly-coloured. The arrangements of Nature in these cases, it will be observed, are simply such as to favour the distribution of the pollen—its light and dusty character and enormous quantity, and the loose manner in which either the anther itself or the catkin is suspended. The quantity of pollen in some of these unisexual plants is illustrated by the clouds of smoke, as it looks like, which rises from a yew tree if struck with a stick or violently agitated by the wind at the time of flowering, giving it the appearance of a burning bush. Travellers state that the waters of some of the large American lakes, as Lake Michigan, are covered at certain periods for a considerable distance near the shore by a thick stratum of a viscid sulphur-like substance, the pollen of the pine forests, which must have been brought by the wind from a distance of several miles. It is generally believed—though on this point further experiments are still wanting—that our cereal crops, especially wheat, rye, and barley, are fertilised exclusively by the agency of the wind. The flowers are small and uncoloured, without calyx or corolla; the anthers are hung lightly on the end of long slender filaments; the pollen is very fine and powdery; and insects are hardly ever seen to visit them. Favourable weather (fine and sunny with light breezes, and yet not so strong a wind as to disperse the pollen to too great a distance so that it will not perform the purpose for which it was designed) at the time when the plants are in flower—*i.e.*, in the early part of June—is therefore of very great importance for the insuring of heavy crops.

But the cross-fertilisation of plants by the agency of the wind is not nearly so common, nor is it a phenomenon so striking or interesting to the ordinary observer, as cross-fertilisation by insect agency. In a large number of flowers the individual pollen-grains are so heavy, or they are connected together by fine threads or by a sticky glutinous substance, that it would be quite impossible for the wind to effect their transport; and in these cases Nature has recourse to her gigantic army of insect workers to do this service for her. It is in seeking for their own food, which consists in a number of classes almost entirely of the juices of flowers, that insects perform this service to the vegetable world; and the modes adopted to allure them are two-fold, the very points which render flowers so attractive to our senses—the beauty of their colour, and the beauty of their scent.

That portion of the food of insects which they obtain from the vegetable world is almost always in the fluid state—the sweet juices of plants contained in various parts, but especially the flower. That part of the flower in which this liquid juice or honey is secreted is called the nectary, and occupies the most various positions in different flowers. In the large flowers of the Crown Imperial there is a deep pit at the base of each petal, containing large drops of honey. When the flower is in the form of a tube or bell, the bottom of this tube or bell is very commonly occupied by the nectary, as in the *Salvia*, or very often there is a small nectariferous gland at the base of each stamen. In the Hellebore two of the petals themselves are converted into nectaries; in other flowers some of the stamens; in fact, any part of the flower may be adapted to this special function. It is to this sweet secretion that odoriferous flowers generally owe their scent; and the very same property which induces us to cultivate them attracts also to them the insects in search of their food. In bright sunny weather our Mignonettes, Pinks, Roses, and other scented flowers may be seen to be visited by swarms of insects seeking nutriment from them. The nectary is frequently too deeply concealed in the flower—since it must be protected against the influence of rain and other injurious agencies—for the body of the insect to be able to be brought near it; and hence those kinds which visit the flowers with long tubes are commonly provided with a long proboscis, as may be seen in butterflies, moths, and bees.

But in a very large number of plants which produce sweet juice suitable for the food of insects this juice is not scented, at least to our coarse organisations; and in these cases the chief mode of attraction to the insects is the bright colour o. some part

of the flower, generally the corolla, or, when this is absent, occasionally the calyx. We see from this the reason of the law that may, perhaps, have struck some of you, that very brightly-coloured, or large, conspicuous, variegated flowers are seldom scented, while highly-scented flowers are often inconspicuous, or, if coloured, are, at least, not variegated. We may contrast, for instance, the sweetly-scented Daphne, Primrose, Sweet Violet, Lily-of-the-Valley, Rose, Hyacinth, Evening Primrose, Lime Tree, Mignonette, Amaranth, &c., all with inconspicuous flowers, or, if large and conspicuous, of uniform unvariegated colour, with the brilliantly-variegated but comparatively or quite scentless Fritillary, Pelargonium, larger and smaller Convolvulus, Tropæolum, Mimulus, Ranunculus, Pansy, &c.

We have now seen how the bright colour and sweet smell of flowers aid in attracting to them insects in search of their food; but not yet how this is of advantage to the plant itself. If we notice a butterfly or a bee while rifling the sweets in a flower, we shall see a quantity of pollen-dust almost invariably sprinkled over its head, or other part of its body. This is independent of the great quantity of pollen which hive and humble bees carry away on their thighs, which they purposely rob from the flowers, and which they take home to their nests, where it forms the "bee-bread" which they store up for their young while in the larva state. The arrangement of the parts of the flower indeed is almost always such that when withdrawing its proboscis from the corolla-tube, or other part where the honey is secreted, it must necessarily come into contact with one or more of the anthers, and thus carry off some of the pollen, which it lodges on the stigma of the next flower of the same species which it enters. Thus, in those flowers in which the pistil and stamens are mature at different times, the pollen is conveyed from the mature anther in one flower to the mature stigma in another flower which has opened a little earlier or a little later, and cross-fertilisation is thus effected.

The vegetable kingdom is full of contrivances for this carrying of pollen, by means of insects, and for rendering self-fertilisation impossible, or at least very difficult. In the *Salvia* the anther is at one end of a cross-bar lightly affixed across the end of the filament, the other end of the cross-bar being unprovided with an anther. When a bee inserts its proboscis into the flower, its head strikes against the end of the cross-bar which has no anther, turns it right over, the end of the filament being the fulcrum, and tips the pollen out of the anther on to the back of the insect, and it is thus carried to another flower.

A very remarkable series of contrivances for effecting cross-fertilisation has been illustrated, with great patience and ingenuity, by Mr. Darwin, in the case of our native Orchids, both the common meadow species and those which grow especially on the chalk hills of our southern counties. Mr. Darwin found that if one of these Orchids is covered over with muslin gauze so as to prevent the visits of insects, it never perfects any seed; indeed, the structure of the flower is such as to render self-fertilisation all but impossible. The pollen does not in these plants exist in separate grains, but is glued together into club-shaped masses called *pollinia*, placed immediately above the stigma, so that they could hardly, of their own accord, come in contact with it. These pollinia are attached to a viscid disc at the base. The Orchids are chiefly visited by butterflies and moths. When one of these inserts its proboscis into the tube of the flower which contains the honey, its head necessarily strikes against this viscid disc, which it detaches and carries away with the pollinia adhering to it. In Darwin's admirable work on the "Fertilisation of Orchids," a masterpiece of experimental research which every one interested in the subject ought to read, is a drawing of the head of a moth, which he actually captured, with quite a number of these pollinia adhering to it. After the removal of the pollinia a very curious change takes place in their position in consequence of their exposure to the air. After a few minutes' exposure the viscid substance at the disc sets, or becomes hard, and in so doing changes the direction of the pollinia from vertical to nearly horizontal. The result of this is, that when the moth, with one of these pollinia attached to its proboscis, enters another flower, it must necessarily strike the pollinia against the stigma, and thus detach a sufficient quantity of the pollen of which it is composed to ensure the fertilisation of the ovule. All these processes may be followed by removing the pollinia from the flower of any common Orchid by means of a pin or fine pencil, instead of the proboscis of an insect.

In *Coryanthes* the contrivance is still more remarkable. "The Orchid has part of its labellum or lower lip hollowed out into a great bucket, into which drops of almost pure water continually fall from her secreting horns which stand above it, and when the bucket is half full, the water overflows by a spout on one side. The basal part of the labellum stands over the bucket, and is itself hollowed out into a sort of chamber with two lateral entrances. Within this chamber there are curious fleshy ridges. The most ingenious man, if he had not witnessed what takes place, could never have imagined what purpose all these parts serve. But Dr.

Crüger saw crowds of large humble-bees visiting the gigantic flowers of this Orchid—not in order to suck nectar, but to gnaw off the ridges within the chamber above the bucket: in doing this they frequently pushed each other into the bucket, and their wings being thus wetted they could not fly away, but were compelled to crawl out through a passage formed by the spout or overflow. Dr. Crüger saw a continual procession of bees thus crawling out of their involuntary bath. The passage is narrow, and is roofed over by a column, so hat a bee, in forcing its way out, first rubs its back against the viscid stigma, and then against the viscid glands of the pollen-masses. The pollen masses are thus glued to the back of the bee which first happens to crawl out through the passage of a lately-expanded flower, and are thus carried away. When the bee, thus provided, flies to another flower, or to the same flower a second time, and is pushed by its comrades into the bucket, and then crawls out by the passage, the pollen mass necessarily first comes into contact with the viscid stigma, and adheres to it, and the flower is fertilised. Now, at last, we see the full use of every part of the flower—of the water-secreting horns, of the bucket half full of water, which prevents the bees from flying away, and forces them to fall out through the spout, and rub against the properly-placed viscid pollen masses and the viscid stigma.

"The construction of the flower in another closely-allied Orchid, the *Catasetum*, is widely different, though serving the same end, and is equally curious. Bees visit these flowers, like those of the *Coryanthes*, in order to gnaw the labellum; in doing this they inevitably touch a long, tapering, sensitive projection, or, as I have called it, the antenna. This antenna, when touched, transmits a sensation or vibration to a certain membrane, which is instantly ruptured; this sets free a spring, by which the pollen mass is shot forth like an arrow in the right direction, and adheres by its viscid extremity to the back of the bee. The pollen mass of the male plant—for the sexes are separate in this Orchid—is thus carried to the flower of the female plant, where it is brought into contact with the stigma, which is viscid enough to break certain elastic threads, and, retaining the pollen, fertilisation is effected."*

To illustrate the extraordinary variety in Nature's contrivances, it may be mentioned that one species—the curious Bee-Orchis of our chalk hills—offers a remarkable contrast to this ordinary

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* Darwin: "Origin of Species." Sixth Edition. Page 154.

arrangement. This Orchis Darwin has never, after the most diligent research, seen to be visited by insects; and it must, consequently, be self-fertilised. Accordingly, its pollinia are found to be of different structure to those of other members of the family. Instead of standing stiff and upright, they have much longer stalks than is ordinarily the case, which, when mature, are flexible, and cause the pollen-masses to hang down in front of the stigma, against which any breath of wind would cause them to strike, and thus bring about self-fertilisation.

It would seem as if different kinds of insects have a partiality for different kinds of flowers, and even for different colours. Plants with very large bell-shaped flowers are fertilised chiefly by large moths belonging to the tribe of sphinxes, and by large beetles of the cockchafer or rosechafer kind. The largest flowered of European plants—the Pœony, the Rose, the large white Convolvulus of the hedges, and the Evening Primrose—are fertilised in this way. The Evening Primrose, which opens about sunset, is visited by the largest kinds of night-flying moths, which are attracted from great distances by its delicate scent. The connection thus opened out between the animal and vegetable worlds, and their mutual dependence one on another, is almost infinite. Many plants would appear to depend for their fertilisation on the visits of one particular insect, native to the district where it grows; and, therefore, if transplanted to another country or another climate where this particular insect is not found, although they may flower abundantly, they will not produce fertile seeds. The American Yucca, for instance, which flowers with us but never bears fruit, has lately been found to owe its fertilisation to a particular species of moth which has its proboscis extraordinarily modified to obtain the nectar from the flowers of this plant only. Many of the exotic plants grown in our gardens, though thriving and flowering freely, are never known to produce seeds, doubtless from the absence of the insects specially adapted to fertilise them. This is the case with the Yellow Jessamine, so commonly seen flowering in the depth of winter, a native of Japan, and with the *Calycanthus*, or All-spice Tree.

There is a species of Orchis with the nectary of prodigious length (eleven inches and a half have been measured in specimens cultivated in this country), called, from this circumstance, *Angræcum sesquipedale*, which long taxed Mr. Darwin's ingenuity as to the mode by which it could be fertilised, the nectar only occupying one inch and a half of the whole length of the nectary. He predicted, in his "Fertilisation of Orchids," that

an insect must exist in its native country (Madagascar) with a proboscis long enough to reach to the bottom of the nectary; and, quite recently, this has been proved to be actually the case.

The geographical limits of the natural distribution of many plants are again fixed rather by the distribution of the insects which fertilise them than by the climatic requirements of the plants themselves. Local botanists state that in this district of South Lancashire many wild plants are not found, or only very rarely, which are extremely abundant with us in the south of England, such as the *Laminum album*, or White Dead-Nettle, the *Convolvulus arvensis*, or Smaller Bindweed, the absence of which can only be accounted for on similar grounds, there being nothing in the climate or soil to prevent their occurrence.

One of your best local botanists, Mr. Grindon, states that the fragrant Labiates (every Labiate, in fact, that yields powerful odour) are wanting, except *Stachys sylvatica*, and the Wild Thyme in one or two very rare localities. The white Dead-Nettle, the Hounds-Tongue, the Sweet Violet, the *Plantago media*, all among the commonest of common plants in the southern countries, are here all but entirely absent. The two common Mallows are very rarely seen, the common Bindweed never; the Cowslip is extremely local; the Comfrey is unknown, as also is the commonest of the Wild Poppies. On the other hand, some splendid plants, like the Giant Bell Flower *Campanula latifolia*, hardly known in the south, are here very common.

As you travel from a more southern clime northwards, one class after another of insects disappears, and with them the plants which depend on them for their fertilisation. In Alpine and Arctic countries a number of the native plants, especially the trees like the Birch and the Fir, have very inconspicuous flowers, and are exclusively wind-fertilised; while others have remarkable brightly-coloured or powerfully-scented flowers, like the *Rhododendron*, or Alpine Rose, and the beautiful *Soldanella* and Gentian, which thrust their brilliant sky-blue flowers even through the melting snow, to attract from great distances the comparatively rare insect visitors. Every traveller has remarked the brilliancy of the Alpine flora in May or June, or of that of a country where the flowering season lasts for only a very few weeks, like Palestine; but few have probably speculated on any other reason for this than the egotistic idea that its only purpose was to gratify the eye of the passing traveller.

Darwin, in his "Origin of Species by Means of Natural

Selection," gives a curious instance of the mode in which these different forms of life are inextricably intermingled with one another. The common Red Clover is visited and fertilised only by humble-bees, the proboscis of the honey-bee not being long enough to reach the nectar. The number of humble-bees in any district depends in a great measure on the number of field-mice, which destroy the combs and nests. The number of field-mice is again largely dependent on that of cats; and the nests of humble-bees are therefore especially abundant near towns and villages where cats abound. Hence it may be said, without exaggeration, that to our domestication of the cat is due, to a large extent, the possibility of large clover crops.

The function of fertilising flowers is not absolutely confined to insects in the animal world; spiders and snails also do their part, though to a comparatively small extent. In tropical, and even in temperate America, a large part of this duty is done by humming-birds, which live on the honey obtained from the very long and deep tubes of such flowers as the *Bignonia*, or Trumpet-Flower. Some very curious relationships have been drawn out between the length of the beak of each species of humming-bird and that of the tube of the flower from which it chiefly obtains its food. Humming-birds are also said to have a *penchant* for brilliant scarlet flowers, which are very common in tropical countries, while the colour is very rare among the natives of temperate climates. Among our common wild flowers it would be difficult to name any of this hue, except the Poppy and the little Scarlet Pimpernel.

But there is another important feature in special adaptation for insect fertilisation on which we have not yet touched; and this refers to the variegation of flowers. The large flowers of which we have at present spoken as being chiefly fertilised by insects of the largest kind have been uniform in colour without any variegation, as the Wild Rose, the large White Convolvulus, the Pœony, and the Evening Primrose. There are a large number of other flowers, both larger and smaller, which owe their beauty to variegation, that is, to dots or streaks of a different colour to that of the greater part of the petals. It was pointed out as long ago as by K. C. Sprengel, the botanist of last century to whom I have already alluded, that whatever variegated plant you observe, say the Fritillary, the Mimulus, the Pelargonium, or the Pansy, the streaks or dots will invariably be found pointing towards the nectary, or receptacle of honey; and that, moreover, brightly variegated plants are almost invariably scentless. The conclusion

was irresistible, a conclusion abundantly confirmed by observation, that the variegation is a guide to insects in search of the food in those large flowers in which the guide derived from odour is wanting It has also been observed, as might also have been expected, that variegated flowers are very commonly visited and fertilised by very minute insects, by whom such a guide-post is especially wanted. A very instructive lesson in Nature's economy of resource in not supplying in the same instance two means to the same end, may be learnt by contrasting a number of pairs of nearly-related plants; in each case one having uniform-coloured scented, and the other variegated scentless flowers, as the Primrose and the Auricula, the Sweet Violet and the Pansy, the Musk and the Mimulus, the Sweet-scented Orchis (*O. Conopsea*) and the Spotted Meadow Orchis, and many others.

In the Wild Pansy (*Viola tricolor*) we have a remarkably good instance of the special contrivances intended to aid small insects in their search for honey. The nectary is, in this case, the extremity of two remarkable appendages, which hang down from two of the stamens into the "spur" of the corolla. Of the five petals, the lower and the two side ones have streaks pointing to the orifice in the centre of the flower. When an insect gets inside this opening, it finds it completely blocked up by a ring formed of the five anthers, except just in front, where there is a small opening just large enough to admit its body. Exactly opposite this opening is the thicker end of a wedge-shaped black streak, which conducts the insect right down the style to the very spot where it can reach the nectary. In making the descent, it must necessarily carry off some of the pollen which is discharged from the stamens internally within the ring; and in making the ascent and emerging from the small orifice, it must also, almost inevitably, enter the stigma, which is here a cavity in the upper part of the style, above the ring formed by the stamens. As far as my own observation goes, the Wild Pansy is fertilised only by the Thrips, one of the minutest of insects; but the interesting point is, that both the little opening in the anther-ring and the black streak on the style are wanting in the Sweet Violet, where they are not required, and where fertilisation is effected in quite a different way.

In the few illustrations of my subject which I have been able to bring before you this evening, I trust that I have been able to show you that even in such an apparently simple operation of nature as the fertilisation of the flower, there is a boundless field for careful observation—observation that will amply repay, in the

evidence it will yield of the most beautiful adaptation of purpose to end—of the inexhaustible wealth of contrivance by which every living creature is enabled to fit itself to the special circumstances in which it is placed, and thus indirectly to assist in the harmonious working of the whole of which it forms a unit. There is no pursuit more easily accessible to dwellers in the country than the observation of facts connected with vegetable physiology; no field in which there is still more left to be explored by any careful worker. "The more I study Nature," says Darwin, "the more I become impressed, with ever-increasing force, with the conclusion, that the contrivances and beautiful adaptations slowly acquired through each part, occasionally varying in a slight degree but in many ways, with the preservation or natural selection of those variations which are beneficial to the organism under the complex and ever-varying conditions of life, transcend in an incomparable degree the contrivances and adaptations which the most fertile imagination of the most imaginative man could suggest, with unlimited time at his disposal." And if I may be allowed to say so, in the presence of such an audience as this, to those who dwell in towns (especially those whose employment is the monotonous one of daily mechanical labour), there is no holiday pursuit, no recreation, better adapted to cultivate those faculties of the mind which are not employed in your daily labour; to preserve that even balance of all the mental powers which marks the wise and large-minded man, than the study of the ways of Nature, the examination of those laws, which, in their unvarying constancy, and yet their constant variety, raise us so far above the petty details of our daily life, and teach us that we ourselves also are a part of this stupendous whole; that on our own conduct, on our performing those duties in the world for which we are adapted, even if they appear to be as unimportant as those of the insect visiting the flower, depends the fulfilling of our part in preserving the harmony of the universe.

That great and true lover of Nature, the poet Wordsworth, said—

> To me the meanest flower that blows does bring
> Thoughts that do often lie too deep for tears.

But it requires more than an ordinary appreciation of the harmony of Nature's laws to be able to say with Tennyson—

> Flower in the crannied wall,
> I pluck you out of the crannies:
> Hold you here, root and all, in my hand,
> Little flower, but if I could understand
> What you are, root and all, and all in all,
> I should know what God and man is.

Parasites, and their Strange Uses.

A LECTURE, Delivered in the Memorial Hall, Manchester, on Wednesday November 12th, 1873.

BY T. SPENCER COBBOLD, ESQ., M.D., F.R.S.

LADIES AND GENTLEMEN,—Lest the subject of my discourse this evening should have alarmed some of you who may not unnaturally entertain a horror of parasites and parasitism, I wish to remark at the outset that the study of these creatures is of the highest interest, and really quite attractive. It is attractive because it is full of novelty; yet more attractive because the study opens up to our view some of the strangest biological phenomena of which the human mind can take cognisance; and yet most attractive in this utilitarian age because a knowledge of it brings with it a rich reward practically, enabling us to do effectual battle with some of the many ills of life to which our human flesh is heir. I would have you observe that in order to acquire a satisfactory knowledge of this subject, or indeed to be enabled to interpret aright any of Nature's secrets, you must allow me to say—enter upon all such studies in a right frame of mind. The prime requisite in the study of this subject is a matter of personal and moral discipline. This discipline consists in a rigorous determination on the part of the student to dispossess his mind of all preconceived opinions whatsoever, and in an attitude of child-like simplicity to seek truth only for truth's sake. Those people who with nervous anxiety are for ever seeking to reconcile the conclusions of modern science with the ideas of their forefathers are likely to remain just as ignorant of the true value and significance of Nature's teachings

as all their fathers were. The mind must be absolutely unfettered and free if it would comprehend the facts of this or any other department of science; and in science, as in the military art, our motto must be "Onward."

Let us endeavour, in the first place, to acquire a large, healthy, and rational grasp of the *general*, in contradistinction to the *special*, facts of parasitism. You are aware, doubtless, that we are in the habit of speaking of the plants or the vegetation of any given territory as constituting the "Flora" of that territory. In like manner, also, you are probably aware that we are in the habit of speaking of the animals living in any locality, or occupying any area or territory, as constituting the "Fauna" of that territory. Thus, we have a British Flora and a British Fauna. We have other Faunas and Floras corresponding with various areas over the earth's surface; in this way constituting insular Floras, continental Floras, and so forth. Now, if you would entertain an adequate conception of the relations subsisting between the parasites of which I am now about to speak and their bearers—that is the creatures in which they dwell—you must look upon each individual bearer of the parasites as forming a territory, or an area in which these creatures legitimately take up their abode. This abode is assigned to them for the purposes of their existence; and constitutes, therefore, in the manner I have sought to explain, the Fauna of that territory. Thus we have a human internal parasitic Fauna. The human territory is occupied by parasitic inhabitants, which might, if they could speak, claim as much right to occupy that territory as you and I have to occupy British territory. The human parasitic Fauna indicated on the list before you, represents the different kinds of creatures which may thus separately consider themselves entitled to take up their residence in the human territory. That list only embraces the series of internal parasites. There is also an external group, or parasitic Fauna; but of the animals comprising it I do not propose to speak this evening. Pursuing our simile, we have, in the next place, a canine territory, which is occupied by creatures whose strange names I do not want you to remember; and, therefore, I shall not attempt to explain their precise meaning. You will next observe that I have placed here a list of the inhabitants of the bovine and the ovine territories; or, in plain English, the names of the various species of internal parasites or entozoa of the ox and sheep. So, also, you notice that we have here suspended a list of the internal parasites of the horse. Some of these parasitic forms are drawn and exhibited on the walls of the room; and of

certain of them I shall again speak more particularly. Now, I would have you observe further in this connection, that the creatures which thus reside in the different territories are not all of the same kind: they vary much in appearance, form, and structure.

You will notice in the lists before you that the names of the species of creatures inhabiting these several areas are differently coloured; and that arrangement is designed to indicate the fact that they belong to separate and distinct groups of creatures. Confining our attention to the internal parasites, we call them technically the *Entozoa* or the *Helminths*. Those of you who are not Greek scholars may wish to understand that this term means "life within," that is, internal life, or internal parasites; and, further, I must tell you that those people who specially study these creatures are called Helminthologists. The student of parasites, by whatever name you call him, recognises four principal kinds of creatures which reside in these various territories. They are named respectively (as you see on the smaller list), first, the *Cestoidea*, which means tape-worms; secondly, the *Trematoda*, which means fluke-worms; thirdly *Acanthocephala*, which means thorn-headed worms; and, fourthly, *Nematoidea*, which means thread-worms. I must in the next place explain to you that these are totally distinct classes of parasites; though all four of them possess one character in common, namely, that they reside inside their bearers and not outside. They are therefore, as before remarked, called *Entozoa*, in contradistinction to the external species which are technically known as the *Ectozoa*. All those parasites whose names are coloured red in these lists are what we call fluke parasites; those that are coloured green are called thread-worm parasites; those that are coloured blue tape-worm parasites. We shall now principally concern ourselves with the flukes.

The *Trematoda* derive their name from a Greek word meaning "perforated." The group, termed *Acanthocephala*, is not represented by any resident belonging to the territories placed before you. However, I have brought one drawing illustrating an *acanthocephalous* parasite. This *Echinorhynchus*, as it is called, is a singular-looking creature. It has a large head, narrow neck, and thick body. Its large head is covered all over with hooks. The species here figured is one that lives inside the whale. Other allied species dwell in cetacean animals, which, of course, must needs be "very like a whale." There is one of our domesticated animals which also has the privilege of harbouring a species of

Echinorhynchus.. The animal to which I allude is that delectable creature called the hog. Neither ourselves, nor the horse, ass, ox, sheep, goat, dog, or cat, are liable to have the privilege of entertaining this singular *acanthocephalous* guest. The expression "territory" is so long a word that we find it more convenient to call the bearer of the parasite the "host;" the parasites themselves being the "guests." We shall in future generally adopt these shorter terms. If a person is invaded by a parasite he is said to be the host, because he entertains the guest. Of course the guest is usually an unwelcome one; however, I have known guests of this description cultivated or farmed in the human territory or host. For example, when I was, some years back, performing a number of experimental researches, I required a large quantity of parasites to experiment with; and one human host was kind enough to rear an immense number of these creatures in his own territory for my especial advantage. I usually gave him a shilling whenever he brought me a bottle full. But I said just now that I would explain a little more clearly, if I could, the nature of these three groups, *Trematodes*, *Nematodes*, and *Cestodes*. You must have some general notion of what a fluke consists before I attempt to enter into details. Here is a series of drawings placed before you, collectively representing many different kinds of flukes.

I daresay you would wish to know the meaning of the term "fluke." It is an old word, which signifies anything flat. When a person speaks of a "fluke" at billiards he means that the stroke was a stupid one, or that of a "stupe" or "flat." The North Sea sailors call the divisions of the tail of the whale "flukes;" and when the great whale takes a plunge downwards, up goes the tail, and the sailors then shout out, I'm told, in not very good grammar, "There goes Flukes." These parasites are called flukes, therefore, merely because their bodies are flat. You will probably recognise in this drawing the common fluke, which abounds in cattle and sheep, and gives rise to the formidable disease vulgarly called the "rot." Hundreds, thousands, and millions of sheep sometimes perish in a single year on account of the prevalence of the rot epidemic, and this disorder is entirely due to the prevalence of the parasite in question, which takes up its abode in the liver of the ovine host. Here is a series of other flukes. You will see that after all they are not such very horrible-looking creatures. They resemble so many unrolled and extended leaves. Their beautiful branching organs here exhibited are connected with the digestive system of the animal, forming, in fact, branching stomachs; and

there are other sets of branching organs which form a system of vessels containing a fluid of a peculiar character. I will mention where one or two of these species come from. This (*Fasciola hepatica*) is the one from the common sheep, but occasionally the human host is permitted to have the privilege of entertaining the parasite. It has only been found in the human subject in eighteen or twenty separate instances, and is therefore an extremely rare human parasite. You need not alarm yourselves about this worm. Don't fancy when you are enjoying your mutton that you run any chance of infecting yourselves with this entozoon—nothing of the sort, I assure you. You are perfectly safe. Now, here is another still more remarkable fluke, which fortunately does not exist indigenously in this country. It is called the *Bilharzia*, a name which I gave it in honour of its original discoverer, Dr. Bilharz, who is a physician practising at Cairo. I cannot tell you all about it; but it is a dreadful little creature, giving rise to a most terrible disorder in the human subject. Hundreds of thousands of the eggs of these parasites are sometimes found escaping from the body of a single person. The creature is a true fluke, but it is not so flat as flukes in general. It has, you see, a round body, with a sucker at the anterior extremity. About its internal structure I cannot now speak, because it would take up too much of our time. Here is a little fluke (*Distoma lanceolatum*), also from cattle, and about half an inch long. Here is another pretty little fluke, called *Polystoma*, which has a lot of little suckers. These were once thought to be mouths, hence its name. Here, again, is a beautiful little parasite, residing in the frog. Put it on a slide under the microscope, and you would exclaim, "What a charming creature." It is an exquisite object, only about one-fourth of an inch long. The frog is a host that is liable to entertain a considerable series of guests. Here is a fluke from the hedgehog; beside it is another one from the fox. Here are also two others I had the good fortune to discover between twenty and thirty years ago in a giraffe. You will notice a general family resemblance between this fluke and that of the sheep. They are, as it were, first cousins. The blue lines indicate the digestive system. Now, instead of having a simple stomach, such as we are favoured with, it has a complex series of tubes dividing into a number of little branches, like the ordinary veins of a leaf. You will observe that the branches pass downwards and outwards. In another view of the same parasite you have the water-vascular system represented. So much for flukes.

Now we will examine a few of the next group or series, which is coloured green on the list. These parasites are called round worms and thread-worms. The creatures figured here are illustrations of *Trichina*. You have heard a good deal lately of the flesh-worm called *Trichĭna spiralis;* some persons pronounce it *Trichīna,* but it is more correct to give the second vowel short, in accordance with the Greek root. I wish to point out that these various illustrations represent forms of *Nematoidea,* or round worms. Here is one callèd the *Trichocephalus,* or whip-worm, because it is shaped like a whip. Here are others more resembling common earth-worms, but they have no sort of relation structurally to those inhabitants of the soil. Worms form a most unfortunate and improper collective name for these parasitic creatures; but I suppose we must retain the barbarous nomenclature, as a concession to time-honoured ignorance. There is one more group, namely, the *Cestoidea,* or tape-worms. Here we have a truly singular series of creatures. Most people have heard of such worms; but few will admit that they have seen any. There is one figured which is called *Tænia Mediocanellata.* It is the tape-worm which the human host obtains when he eats underdone beef. It is the most common form of human tape-worm. It is quite a delusion to think that the pork tape-worm is as common as that derived from beef. I can speak quite confidently on this point, because I have investigated the subject carefully. There is the creature represented at full length. It has four suckers, but no hooks. That one over the fireplace is from pork, and is recognised by its head having a series of hooks in addition to four suckers. The tape-worm is a most remarkable creature. It consists of a head and a segmented body, which is sometimes twenty feet long or more. The next question is as to the nature of those joints or segments. Each one of those joints or segments is what Professor Huxley would term a *zooid.* It is a sort of semi-independent imperfect individual. In fact a tape-worm is not a single creature, but a multitude of creatures all arranged together in single file. You probably have some acquaintance with those pretty little objects which are found on the sea-shore—zoophites, polyps, with numerous heads. Now the compound polyp is a colony of individuals branching out like a tree. But here is a colony of polyps ranged in single file like a regiment of soldiers; and thus one long creature is produced by a number of little beings adhering together; some 1,200 individuals being joined together so as to form a colony. The marvellous changes through which that creature passes I have not now time to dwell upon. My present

object is merely to give you a clear and definite idea of the three principal groups of guests that have the privilege of residing in the human and other hosts, and to show that they are essentially distinct both structurally and generally.

Here for the present I pause to ask you a question. In the face of these few data which I have laid before you, can you, I ask, be satisfied with the old and erroneous notion that these parasites are merely the results of disease? Or, again, can you be satisfied with that merely modified conception which would make it appear that these creatures only exist in hosts previously enfeebled by disease? Is it not already palpaple to you that such popular notions as these are utterly unworthy of your regard; that they are altogether out of harmony with other conclusions of a like kind deduced from scientific observation? If you have a whole series of organised beings taking up their residence in territories (granted that they are peculiar territories or areas), each one of which is furnished with organs enabling it to occupy that territory to its own advantage, how is it possible, I say, to be satisfied with those old teachings which assert that all these wonderfully-organised creatures are the mere result of disease? Some persons, indeed, have been foolishly persuaded to look upon these parasites as so many tokens of Divine chastisement! Such an interpretation of natural phenomena is a mere farce. Here, you observe, is a series of natural areas, these areas being respectively occupied by highly-organised creatures, each of which is fitted, most wonderfully, to take up its singular and suitable abode. I speak earnestly on this subject, because I am most desirous (as one who has worked at the subject for many years) that healthy, rational, and true views should be taken up in this connection, and that the old ones should be abolished. You must pardon my freedom if I appear unduly anxious on this point. I entreat you to be guided only by the teachings of reason as opposed to the dogmas of a carefully nurtured and educated ignorance. Whether you deal with subjects of this kind, or whether you are working at certain other departments of science which in some phases are justly considered far more delightful—the charms of such beautiful subjects of study as spectrum analysis must be great for those who pursue them—there are, you may be sure, great lessons to be learnt. Even in the study of these little despised parasites there are teachings to be deduced which are in harmony with those derived from the more attractive sciences. And I would also say in this connection—from conclusions which have been forced upon me by conversation with many who came

to see me about such subjects—that some people's ideas seem so cramped and compressed that they might very well, without much stretch of the imagination, be placed within the circumferential limits of an ordinary nut-shell. But, happily, one delights to think, that in Manchester at least, there are many minds of a far different stamp; so different, indeed, that to speak figuratively, the range of their ideas would require an area whose diameter should extend from this platform to the glorious orb which rules the whole of the planetary system.

Well, now, to pass on to the special part of my subject, let me give you a few details respecting the life history of one or two forms. Perhaps I cannot do better than say something about one I have alluded to already, namely, the little flesh-worm; a parasite which takes up its abode in the human area (*Trichina spiralis*). I hold in my hand a simple microscopic slide, and if this small specimen of flesh were placed under a microscope, you would observe 100 parasites at least. Now supposing the muscles of any human individual were infested with the parasite to the extent represented by this little specimen, you might probably state without exaggeration that he had the privilege of entertaining fifty million guests! In some instances more have been harboured by a single host. I happen to have examined part of the flesh of an unfortunate foreigner, who was killed in the streets of London, and who must, during life, have entertained a hundred million of these guests. If you examine a portion of trichinised flesh under the microscope, or even with a pocket lens, you will often notice an appearance similar to that which is represented in this diagram. You observe here a portion of simple flesh, and a number of little capsules, lemon-shaped and spindle-shaped. In each one of these capsules is rolled up a little flesh worm; so that if you take one and magnify it still more highly, you will get the appearance presented in this second diagram.

Here is one of the *Trichinæ* rolled up inside its capsule. Here is another representation of the same thing from a cat. You observe some eight lemon-shaped capsules, and in each one of those capsules is a little parasite. Now you would like to know some further particulars of the life-record of this parasite; how it gets into the human territory, and, in short, all about it. Those who are fond of underdone pork, and who happen to persevere in eating a quantity of it in the trichinised condition, will assuredly be liable to infect themselves with the parasite. The flesh of the pig is apt to contain these small capsuled *Trichinæ*. They are so small that their length does not exceed the 1-25th of an inch from

head to tail. When the consumer has eaten his meal (our friends the Germans are very fond of eating raw pork) he will, if he has swallowed half-a-pound of flesh, have taken into his stomach many thousands of these little parasites. But they are only larvæ; they are in a juvenile state of development; and you will say, therefore, that they would do him no harm. Far otherwise. Although they are only in the larval stage of development, it suffices for them that they remain inside the new bearer—they are borne from the intermediary host, the pig, to the human being—I say it suffices for them to remain forty-eight hours, for they will by that time have become converted from the larval condition of growth into the mature adult *Trichina*. Their growth is very rapid, and when they have arrived in the alimentary canal of the human bearer or host their size becomes greater, but yet not very great. I have both males and females figured here. The male *Trichina* is only 1-18th of an inch long, and the female, although she is very much larger, only one-eighth of an inch long; so, after all, it is a very tiny parasite. Small though it be, it is able to produce wonderful effects. When they have been comfortably lodged in our interior for six days, by the end of that time an immense number of little *Trichinæ*, the progeny of the full-grown parents, make their appearance. They swarm out of the parent *Trichinæ* by hundreds, thousands, and tens of thousands; thus collectively amounting in a single bearer to many millions. Well, what becomes of them? They have got into the alimentary canal. The embryos are very minute, not more, perhaps, than the thousandth of an inch long in the first instance. Their smallness, their toughness, their strength, and their armed mouths, enable them to bore directly through the walls of the alimentary canal, and thus the progeny is dispersed in all directions. They bore through the tissues and make their way to the surface of the body; they stop at nothing; they pass through almost every structure except bone, until they arrive at the muscles. They even pass through the heart; not finding its muscular substance a suitable permanent residence. During these wonderful wanderings or migrations (for all parasites have a tendency to wander or migrate) you have, as it were, an army of say fifty millions of these liliputian creatures; and the consequence is that the unfortunate host suffers the most agonising pains. He imagines perhaps that he has got the gout or rheumatism, when it has nothing to do with rheumatism or gout, but is simply a disorder caused by the wounds inflicted by these little wretches. And if he happens to have eaten very heartily of the trichinised pig, of course he stands a chance of

being killed by these little creatures What is enjoyment to them is real pain and sorrow to him. When they have bored their way through the tissues (supposing he does not succumb to the wounds inflicted by them) they settle down in his muscles in place of the pig's, and there they make to themselves comfortable residences. These residences show themselves ultimately in the form of little capsules, such as you see figured in the diagram, and there they remain. Then you will say, "What becomes of them?" They simply wait there hoping that some one will come and devour the host; for if anyone should play the part of cannibal (and there are cannibals still in existence), he who played the part of cannibal would in his turn be trichinised. If the human host is not devoured, what happens?. A natural cure is effected. It seems to be the prerogative of nature in all cases where wandering parasites get into the human territory, that they shall live there for a certain time only; this length of time varying with different species, but in all cases, sooner or later, they perish by the process which is called calcareous degeneration—they become converted into little particles of lime; and thus the cure is effected. Such are the strange phenomena undergone by the little flesh-worm. One of the most interesting points about it is the rapidity with which all the processes of development take place. You have these creatures passing from the capsuled condition to the adult condition in two days; from the adult the eggs are given off; their contents in six days more being converted into little embryos, which pass through the tissues of the ultimate bearer to his muscles; so that in a period of three weeks, altogether, the whole life-cycle of the individual is completed. A more marvellous series of changes in the life history of this group of parasites is not to be found.

You must not, if you please, hold me responsible for the precise title of the lecture, this evening. Not that I have to find fault with it; for, perhaps, it was the very best that under the circumstances could be offered. Nevertheless, it may have been a little misleading. You will notice in the announcement that something is said about "their strange uses." Now, that expression—"their strange uses"—I take to be a concession to popular ideas. "Their strange uses!" Are there not, I would ask, some people who really still believe that everything that has been created has been made especially for man's benefit? I do think that there are many who still entertain notions of this sort; and when they see the term, "their strange uses," they perhaps think there must, after all, be something good in these things, or some special purpose in man's favour.

Therefore, you will ask the question, "Could we not get on very well without them?" I certainly think we could. I do not think that there is any necessity that we should be trichinised, or that we should play the part of host to these creatures. Nevertheless, as a matter of fact, hundreds and thousands of people in Germany are trichinised, and scores of persons have perished of late years from the *Trichina*. Then, you will say, "What general conclusion can be drawn from the data given? What is the real part these creatures play in the economy of nature?" The question is applicable not only to these *Trichinæ*, but also to other kinds of parasites, some of which pass through far more astonishing transformations.

Well, that question could be answered in two ways; first, as regards the creatures themselves, and, secondly, as regards the creatures they inhabit. You must meet the question as follows: I would say, as regards the creatures themselves, that the part they play in the economy of nature is none other than that which is played by all carnivorous animals; for, as it was admirably put by Professor Leuckart some years ago, whenever an animal is too weak or insufficiently armed to overcome and destroy another creature, to which, or upon which its instincts direct it to seek for food and nourishment, then it must content itself by robbing the juices of the creature, its flesh, its blood, or its tissues. The only difference between a tiger and our little *Trichina* is, that the tiger kills his victim by a single blow (in the island of Singapore 400 natives are killed annually by tigers), but it sometimes takes one hundred millions of these *Trichinæ* to overcome the host which it inhabits and victimises. The tiger kills the man to obtain its food; the *Trichina* penetrates the human frame to seek its food; and there is no essential difference between the tiger and the *Trichina* in this matter. The part they respectively play in the economy of nature is one and the same. It is a strange reflection! Then there comes the question as regards the bearers themselves. Well, I am bound to say again that there is no evidence to show that any one of the numerous creatures which infest these various hosts is in any way beneficial to them; not in the slightest, except—there is, it is said, no rule without an exception—except in a ludicrous sense. Well, let us take the human host. I have said that we not only entertain internal guests, but sometimes there are external guests, and this is the ludicrous phase of the subject. When residing in a part of London near Portman Square, I happened to take up my abode in a house wherein dwelt what we call *Ectozoa*—parasites which are liable to attack not the interior

out the exterior. This necessitated my sending to some skilled man who professed to be a perfect "insect destroyer"—in fact, a destroyer of the pest which, in musical phraseology, is sometimes called, very significantly, the B flat. And it happened whilst he was in the house that a lady, somewhat injudiciously, but very naturally, remarked that she could not think for the life of her why these nasty things were created. Whereupon this worthy man, who rejoiced in the function of destroying *Cimex lectularius*, replied—drawing himself up as if his dignity were offended—"And what ma'am should a poor fellow like me do for a livelihood if the Almighty hadn't made 'em?" So that you see there is a possibility of some parasites, external if not internal, being useful to certain members of the human race.

Well, but seriously, let us try and tackle this matter a little more closely, for I know it is one of those subjects which, when handled by people entertaining what may be called old ideas, is very apt to produce an unfavourable effect upon the mind. Brought up in the notions of the past, such a person does not like to think that these creatures can have been expressly made to occupy the human and other territories. It seems queer to him that human beings should be infested by horrid parasites, which as they pass through his tissues give rise to pain and trouble; and he is at first inclined, perhaps, to set up a sort of non-Providence theory, and to say, in effect: "Well, that cannot be a very benevolent purpose which has animated the author of these creatures. What can be the meaning of it?" Now I have a sympathy with people who think in this way, because I once thought so myself. And I daresay that the poet James Montgomery hit the mark very closely, when in his poem, "The Pelican Island," whilst referring to the habits of carnivorous animals, and taking the old point of departure, he wrote:—

> Harsh seems the ordinance that life by life
> Should be sustained. And yet when all must die
> And be like water spilt upon the ground
> Which none can gather up, the speediest fate,
> Though violent and terrible, were best.

Those were the ideas of Montgomery, and I certainly think that they accord with some of our own. This, as I said before, is just one of those subjects which ought not to be handled by narrow-minded persons. Anyone who studies parasites and does not acquaint himself with what is going on in other more noble fields of science around him is very apt to get contracted views of the economy of nature—is very apt to have small notions as to the

why and the wherefore anything was created. But if he will reflect awhile, if he will think of the thousand and one blessings which surround him; if he will reckon up all the multifold advantages which he enjoys as the highest of the creatures occupying this planet, and add up the group of ills on one side and the advantages on the other, then I apprehend (unless his mind is a wretched little one) he will come to the conclusion that on the whole we have much to be thankful for.

If you do not see this, allow me to press it further by evidence before us. Here, in common with the canine, ovine, and bovine hosts, we share what I call, speaking figuratively, the privilege of entertaining a series of parasites. It is very rare that we have more than one of those visitors or guests at a time, very rare; but see now the advantage that we have over animals. Here we are, placed on a planet which has undergone marvellous changes, and representing the highest outcome of a whole series of developments throughout geologic time; and we share now with these animals this peculiar and disagreeable prerogative. But mark you the difference. Whilst animals are liable to be thus infested, they have not the possession of such a reason and power of acting upon it as we have. Would that the gift were more exercised! We have put into our hands an instrument—this reason—by the aid of which we can not only cure ourselves, or be cured of disorders which are caused by these parasitic creatures when they invade us, but what is better than that, we have—by the aid of science and by no other kind of teaching you may be sure—we have, I say, hit upon a method of preventing these disorders. It is therefore obviously and clearly our own fault if we suffer largely from parasitism. Those only who delight to stifle the intellect and who would prevent us carrying out our researches, are responsible for many hindrances in this connection. Since we have thus a clear advantage over "the beasts that perish," I hold that we ought to rejoice in the elevated position we occupy. At all events, you may be sure that in viewing such questions as these the larger range of vision you take the more likely are you to arrive at a healthy deduction from the recognised facts.

I see I have a little more time, and, therefore, I will explain something specially peculiar and interesting. You will remember I alluded to the tape-worm as a colony of individuals ranged in single file, and I spoke of the beef tape-worm in particular. I have performed a series of experiments, and those experiments have resulted in giving us a more perfect knowledge of the entire life-history and mode of development of that singular creature.

For instance, I will detail to you one kind of experiment I made. I took a portion of such a tape-worm as you see there, comprising several of those joints or segments towards the tail end. Now each of those joints when perfectly ripe or matured contains 30,000 eggs; therefore, you can easily reckon up how many there would be in 12,000 joints, supposing all were mature. I took a number of those joints, I say, and put them into milk to make them easy of administration, and with the assistance of friends fed a calf with them. Well, they went down, and the calf was none the worse apparently. However, after a time—I won't describe to you the symptoms—it was quite evident that something had happened. Now what had happened was this. Some thousands of eggs had been swallowed. Of those eggs all that were perfectly ripe contained in their interior each a little creature called the six-hooked embryo. This small embryo has a round body, provided with two needles in front, and a pair of hooks on each side. With the two little needles it bores, and with the two pair of hooks, placed at the side, it tears the flesh of the host. When the calf swallowed the eggs, which were conveyed into the fourth stomach, the shell of each little ripe egg was dissolved by the gastric juice; all the little embryos thus making their escape. This was, you see, kindness to the embryos if it was unfair to the calf—communicating pleasure to 30,000 at the expense of one. I believe that principle of action in politics is a good liberal cry—"good to the many." I hope that similar ideas will be found to animate those who have been elected to-day by your suffrages. The thousands of little creatures, rejoicing at being set free, swiftly made their way through the tissues of the host. The little calf did not succumb to these wounds, as the human bearer often does to the trichinæ, but by our assistance it recovered. Well, we calculated how long it would be before these little embryos would arrive at the higher larval stage of development; and we had indications afforded us that it would be three months. So at the expiration of three months, our calf, which was now a strong animal, was slaughtered—for the market you would say, perhaps. No, not for the market. It was slaughtered in the cause of science and humanity; and when we removed the external parts, it was found that all the muscles, especially the superficial ones, were filled with the higher larvæ of this parasite. This larva, measle, or bladder worm, is called, scientifically, the *Cysticercus bovis*.

Now the little larva, when examined, presented an appearance such as is figured here. I have here also drawings of the heart of the calf, and you perceive that the whole surface of it, and also

the interior of the organ, is swarming with these little larvæ. Thus we reared in this calf many thousands of these parasites. Now observe—supposing we had sent that calf to market, what would have happened? Every individual who partook of the veal, and who did not in cooking raise the temperature to 145, would undoubtedly have been liable to have had developed in his interior the adult form of this particular parasite. How do we know that? We have experimental proof in various ways. A gentleman in India has lately had the ccurage to induce a Mahomedan boy to swallow some underdone meat of this description purposely, and the result was that the boy had the privilege of playing the part of host to as many tape-worms as he had swallowed examples of this little cysticercus. I hold in my hand the largest specimen I have ever seen; it was brought from India, and was taken from meat served out to our troops there as rations. What happens when the measles are swallowed is this—the bladder-like part is immediately digested, but the head and upper part of the neck are not digested. These latter pass down from the stomach into the alimentary canal, and the head, by means of the suckers with which it is furnished, then adheres to the lining membrane of the alimentary canal. Then a process of budding commences, and in three months the worm would be fully developed. Now you cannot help observing that such astonishing phenomena as these are not the result of disease or accident; they constitute together the life cycle of a creature expressly organised to lead a parasitic mode of existence.

I never yet heard of an English butcher who had ever seen one of these parasites; and yet, I am in a position to say that at this moment at least 10,000 persons in this country are playing the part of host to these creatures. Butchers are profoundly ignorant people in this respect. Then you will say, "How do the cattle get the parasites?" I will explain. Millions of these creatures pass from their human bearers every day in this country, with other things that are vile. You know that Shakespere says, "Evil things do fastest propagate." These evil things make their way into the sewage which it is now the fashion to spread over the land far and wide, and they are thus distributed in millions amongst the delightful verdure on which the cattle graze. The eggs are thus often taken into the mouths of animals along with their fodder. Every egg thus swallowed from fresh sewage becomes a measle, and every measle that is in the flesh of the animal goes to the market, is sold and eaten, and is afterwards converted into a tape-worm; provided the purchaser does

not take the precaution of having the food properly cooked. Here is the value of reason. The animal does not thus reason; neither does it cook its food. To avoid these things you must simply have the food well cooked. Do not flatter yourselves that partial cooking will destroy them. A heat of 160 degrees will be perfectly sufficient, if prolonged, to kill even that disagreeable little creature *Trichina spiralis*. If the heat goes to boiling-point you are perfectly safe; but you know that it takes a long time for a joint to become heated to 212 degrees in the inside. Therefore, the rule is prolonged cooking, and then 140 degrees are sufficient to prevent infection from *Cysticercus*, and 160 degrees for *Trichina*, from which latter there is more danger, seeing that they are enclosed in little protective capsules. Allow me to say one or two words by way of encouragement. In this country we have only once had an outbreak of *Trichina* disease, and that was in Cumberland, and quite lately. Abroad this subject excites much more attention, because the habits of the people favour the development of the disease.

It is perfectly possible for those who study this subject to create an epidemic of these diseases; so I recommend you to keep us Helminthologists in good humour, for we could, in revenge, decimate the population of any town in a certain number of months by the distribution of the germs of parasites.

Such are the results of scientific research. Strange and harsh may sound some of the things I have said; but is it not best to face all difficulties and to tell the whole truth and nothing but the truth—to conceal nothing, but to explain everything openly? I rejoice to have had the privilege of addressing an audience in Manchester, because I was told in London, just before I started, that the people of Manchester had a real sympathy for those who promoted science—for anything, in short, which could benefit humanity in the largest sense of the term. From the highest and best of motives we know that there are people ready to spend their hundreds and thousands in the propagation of ideas which are essentially small, not to say morbid; but how few contribute their aid to advance ideas which are for the advantage of the whole human race? I hope that these few parting words will be accepted in the spirit in which they are uttered. I look upon this matter of teaching and giving lectures in public as really a serious thing. We pledge ourselves to the truth; we are earnest men. The gentlemen who are promoting these discourses are effecting a good the end of which they will not live to see. These beginnings are like the

little cloud in the distance no bigger than a man's hand, which in ages yet to come, will develop into large clouds, sending down refreshing showers, that shall spread intelligence and life and knowledge over the whole surface of the earth.

I see my time is up; I can only say therefore, in conclusion, that if I apprehend rightly the essential objects of these lectures, they may be appropriately summed up as those of mutual improvement and the investigation of truth, the development of the seeds of knowledge and the detection of falsehood, the emancipation of the mind from the fetters of ignorance, and the cultivation of a ıe humanity by social gatherings and intellectual discourse.

GUN COTTON.

A LECTURE, Delivered in the Hulme Town Hall, Manchester, on Wednesday, November 19th, 1873.

BY F. A. ABEL, ESQ., F.R.S.

BEFORE I say a word to you about gun cotton, I should like to call your attention, for a few moments, to a substance with which it has, during the last forty years, attempted to stand in rivalry, namely, gunpowder; because I believe that if I can in a few words make you understand the nature of gunpowder, that of gun cotton will be much clearer to you afterwards. Now, gunpowder consists of three substances very intimately mixed together—the substance charcoal, made by charring wood; sulphur, a substance found in its elementary or native condition, and also extracted from several minerals; and saltpetre, a natural product originating in the gradual decomposition of a variety of vegetable and animal substances. Now, when gunpowder is subjected to the action of heat, or contact with flame, with a spark, or red-hot body of any kind, the following results are produced: both charcoal and sulphur are very readily oxidisable, or eager to burn at any time. We know how readily a piece of wood kindles when it is heated to a sufficient degree in air—we know how much more readily a piece of sulphur burns; both of them combining with a certain portion of the air which we call oxygen; and, therefore, we call these two bodies "combustible" bodies—charcoal, occurring in wood, and known to the chemist as carbon; sulphur, a substance extracted from various minerals.

These two bodies burn very readily if we heat them in air: they burn still more readily if we heat them in oxygen, or if brought into contact with some substance which is ready to give

its oxygen to them; and this oxygen is derived, in the case of gunpowder, from the substance saltpetre. Saltpetre is a body which contains a large quantity of oxygen. It holds this oxygen in what we chemists call a feeble state of combination; that is to say, it is ready to give this oxygen to other substances greedy of it. And, therefore, if we heat sulphur or carbon (charcoal) in contact with saltpetre, it gives up to these bodies the oxygen which they require to burn, and then they burn rapidly and are converted in the course of that burning into gaseous substances. In passing from the state of solid to the state of gases, they assume many times their original volume; and at the moment at which they pass from the solid to the gaseous state a quantity of heat is generated by the chemical action that takes place between these substances. The result of all this is that the original solid mixture becomes expanded to very many times its volume, and this transformation occurs with great rapidity.

The almost sudden conversion of a solid, occupying little space, into gas occupying a great space, and which is, moreover, highly expanded by the heat developed during the transformation, gives rise to the development of a large amount of force, which has the power of overcoming great obstacles, or impediments to the violent expansion of the substance. The sudden or very rapid transformation of a solid or liquid into gas or vapour is generally productive of noise, and is attended by some more or less violent demonstration of force. It is called an explosion; and any substance which is susceptible of undergoing such transformation suddenly or very rapidly on the application of heat, or other disturbing cause, is called *explosive*. Therefore we call gunpowder an explosive substance.

Now the oxidising or burning component of gunpowder—saltpetre—contains a metal possessed of some very interesting properties, into which I cannot now enter; and this metal holds in combination with it a substance consisting of nitrogen combined with a large quantity of oxygen, both of which are gases existing in the air, as you may remember. Oxygen is ready to escape in the form of gas from any compound in which it is contained in a solid condition, combined, but not very strongly, with other substances. Thus, if we heat this saltpetre sufficiently, we can make it give up its oxygen without the assistance of the sulphur or the charcoal. If we continue to heat it very strongly we can also liberate the nitrogen from it. But if we heat it only moderately, when mixed with some substance which has a very great liking for the metal it contains, such as this powerful acid.

known as oil of vitriol, we then obtain from this saltpetre, not oxygen and nitrogen separately, but a combination of them with water—a fluid called nitric acid, which used to be called by old chemists *aquafortis*, or strong water, on account of its highly corrosive properties. Now nitric acid behaves very much in the same way towards sulphur and charcoal as the original saltpetre does. If we drop a piece of saltpetre upon red-hot charcoal it begins to deflagrate; that is, the charcoal begins to be burned very violently by the oxygen contained in the saltpetre. If we allow a drop of this nitric acid to fall upon red-hot charcoal, the action is just the same as if we allowed saltpetre to fall upon it. Nitric acid acts upon substances which are easily burned or oxidised even more readily than saltpetre. It does not require the assistance of heat to such an extent to develope its action, and to cause it to burn up the sulphur and charcoal. This nitric acid is manufactured by putting saltpetre and oil of vitriol into a retort together and applying heat, when this most valuable chemical agent distils over as a pale yellow fuming liquid. It is one of the most useful agents in manufacturing and scientific chemistry. I hope now I have made you understand generally what gunpowder is, and what nitric acid is, and, if so, I believe you will have little difficulty in understanding what gun cotton is. I will, therefore, proceed with my history of this remarkable substance.

About forty years ago some new substances were first produced in France which excited considerable curiosity amongst chemists. They were obtained by acting, with the highly corrosive liquid which we obtain from saltpetre, upon the well-known substance, starch, and upon cotton fabrics, such as muslin or calico, and even paper. When cold nitric acid was added to starch this substance was dissolved, and, upon adding water, the starch appeared to be separated again, but it had no longer the properties of the original substance—it had become endowed with explosive properties. When muslin or paper were dipped into nitric acid, allowed to remain for a very short time in that liquid, and then taken out and washed, though they appeared to be unaltered in character, except that they had become somewhat tender, there was a most remarkable alteration in their chemical properties, for, instead of being simply inflammable, that is, instead of burning quietly when set fire to, they burned very rapidly after this treatment, and almost with explosive violence. I have here specimens of paper and of calico which have been submitted to this kind of treatment, and you perceive how very quickly and brilliantly they burn. [The lecturer ignited the paper and muslin, which were instantly

consumed. These and numerous subsequent experiments were very successful, and were much applauded.]

The discovery of these substances was very interesting, because they were really the foundation of the discovery of gun cotton. About fourteen years afterwards a German chemist, Schönbein, found that if common cotton wool was submitted for a short time to the action of cold very strong nitric acid, its weight was increased about 80 per cent; that is, 100 parts of the original cotton, after having been steeped in acid and washed and dried, furnished about 180 parts of what still appeared to be cotton wool. But this substance, when thus treated, was found to have the properties of the paper and muslin products which have been described, only to a more marked extent. Here is a portion of finely-carded cotton wool which has been treated in this way. As you perceive, it burns almost instantaneously. We observe no smoke; and, if we light a piece upon a perfectly clean plate, we shall find that there is nothing left—that the whole goes off in the form of gas and vapour. Gunpowder, when it is set fire to, leaves a considerable black residuum, which consists of certain solid substances formed besides the gases, which are generated as I have described. You have noticed how rapidly this gun cotton burns. It burns so very rapidly that, if I am successful in the experiment—which I never fail in when performing it by myself—I may even wrap some grains of gunpowder in gun cotton, which, when set fire to, will burn, leaving the gunpowder unburnt, simply because the gun cotton burns so rapidly that there is no time for the flame produced to set fire to the mixture of charcoal, sulphur, and saltpetre. [Experiment.]

Now, this gun cotton ignites at a very much lower heat than gunpowder, which will not inflame at a heat lower than that at which sulphur begins to burn, about 560 degrees on Fahrenheit's scale, and will then only ignite gradually. Gun cotton will ignite at a temperature of about 300 degrees Fahrenheit, which is still a high temperature, though very low as compared with that at which gunpowder inflames. I will heat a small quantity of this gun cotton in a tube, which I have lightly closed with a cork. You see in how very short a time the gun cotton ignites, with a slight explosion, accompanied by a sudden flash of flame, which I daresay many of you did not see, as you were not prepared for it.

There is another peculiarity about gun cotton when compared with gunpowder, namely, that it is comparatively readily ignited by a blow. I say comparatively, because, though

it is really not very readily ignited, it is much more easily exploded in this way than gunpowder. I will wrap a small quantity of gun cotton in this piece of tinfoil, for the purpose of confining it, and then give it a smart blow, after a gentle tap or two, and we shall hear a loud noise, showing that the gun cotton has exploded. In order to insure the production of this most highly explosive gun cotton the nitric acid used is first mixed with a large proportion of the strongest oil of vitriol, or sulphuric acid. The effect which this has is twofold: firstly, the nitric acid itself is rendered stronger, as will presently be shown, and, secondly, the oil of vitriol appropriates water which is set free during the production of the gun cotton, and which, were it not so appropriated, would reduce the strength of the nitric acid. Oil of vitriol is very greedy of water, and if exposed to the air the oily liquid gradually becomes thinner and thinner from the absorption of moisture which exists in the air. If we mix this liquid with strong nitric acid (which, however, still contains water), it is made stronger still, because the water goes by preference to the oil of vitriol.

I will dip this cotton wool into a mixture of nitric acid and oil of vitriol, and take care to keep the mixture quite cool. This is necessary, because when any chemical change takes place heat is developed, and it is necessary to remove this heat by keeping the mixture cool, in order that the heat may not establish other chemical changes. You have seen that heat has the power of establishing violent changes.

The cotton sustains no change in appearance by this treatment, as I have said, but it has greatly increased in weight. A definite quantity of water is set free from the cotton, which consists of carbon, hydrogen, and oxygen. A corresponding quantity of the nitric acid elements pass into its place, weighing much more than the water displaced. In this way a large quantity of oxygen is introduced into the cotton, which is ready at any moment, when the necessary impulse is imparted, through the agency of heat or a blow, to form comparatively simple gaseous compounds with the carbon (or charcoal) of the cotton wool. At the moment of such change the hydrogen and oxygen contained in the cotton are liberated as vapour of water, and the nitrogen from the nitric acid escapes as gas. This is how cotton becomes transformed into an explosive substance.

If we employ a weaker nitric acid (or acid mixture) we shall obtain gun cotton of a less explosive character, as I think you will see when I set fire to this particular kind of gun cotton which has

been produced by weaker acid from cotton wool. You see that that is a very poor explosive substance as compared with the first sample. This less explosive gun cotton possesses, however, some peculiar and valuable properties. It is readily soluble in a mixture of ether and spirit, or alcohol; which mixture has no effect upon ordinary gun cotton. I add some of the mixture to the less explosive gun cotton, and you see that it is nearly dissolved already.

The liquid I obtain in this way is that valuable preparation known as collodion, which, besides having important medical uses, is an invaluable agent in photography. When we allow the solvent to evaporate, the gun cotton is deposited in the form of beautiful transparent films, of which I have specimens here. You see they are only very slightly explosive. This substance is used for the production of transparent films upon glass plates or paper, so as to make them sensitive to light, through the aid of certain chemicals which are dissolved in it. I shall have an opportunity at the close of the lecture of showing you illustrations of this application of one of the forms of gun cotton.

Now, when the German chemist discovered the facts I have named, he saw at once that the highly explosive gun cotton might become a very useful material if its explosive power could be tamed. I say "tamed," because, as you have seen, it is a very violent explosive substance. Schönbein saw that if it could be tamed it might possess considerable advantages over gunpowder, from the fact of its leaving no residue, whilst gunpowder leaves a quantity of dirt, and from the fact of its giving no smoke. It also appeared to promise other advantages; but neither its German discoverer, nor the English and French chemists who at that time experimented with it, were able to realise their anticipations of making it take the place of gunpowder. Amongst the earliest experimenters and manufacturers of gun cotton were the great powder-makers, Messrs. Hall, of Faversham, in Kent. They established works for its production, and made some attempts at its application. They soon observed that gun cotton was too bulky, and that if it was to be utilised it must be compressed. They did not probably fully appreciate the full importance of their endeavours in compressing gun cotton into a small space. Here is a cartridge made by these gentlemen in 1846. It is a case like a Roman candle, made of paper, and rammed very tightly with gun-cotton wool, compressed to such an extent that this case is very heavy, and weighs nearly as much as it would if filled with gunpowder. Well, by this act of compression very important

results were attained, for compression at once modifies the character of gun cotton as an explosive agent. You probably will laugh at me when I say that if we compress this violently explosive material sufficiently, we can make it non-explosive—that is, stop its burning altogether. I will try to show you this, but I do not know that I shall succeed. I have here a piece of gun cotton, which I will compress very firmly at one part by means of this card, and then set fire to it. You see, burning stops at the point where I have compressed the gun cotton, and the rest of the piece is all safe. This proves that if I sufficiently compress gun cotton it will stop its burning. I shall have to inquire directly into the cause of this. I must first finish the history of gun cotton in its first form, that of wool, by telling you that, although its discovery was received with great enthusiasm by military men in England and France, and to some extent also in Germany, factories being established for its production upon a large scale, with a view to test its applicability for all kinds of purposes, a number of serious accidents, attended by loss of life, occurred within a short period, and there arose in consequence such mistrust of the character of the new explosive agent, that within two years of its original discovery its manufacture and the attempts to apply it as a substitute for gunpowder were utterly abandoned.

The fact is, that at that time the makers of gun cotton were unaware of the great importance of thoroughly purifying the substance in order to ensure the permanence and stability of its character, or its freedom from such liability to undergo changes, which might lead to its spontaneous explosion, as to enable it to be as safely handled as gunpowder. If a small quantity of free acid is allowed to remain in gun cotton, this acid will, after a time, begin to exert chemical action, or carry on the action which was interrupted by the washing of the cotton; and this action will proceed until the gun cotton loses its original properties altogether and passes into a kind of gum, of which I have a specimen here. This is gun cotton which was made about ten years ago by an operator who did not understand this very important matter of thoroughly purifying the cotton, and it has consequently passed into the gummy material which you see. But this change or decomposition of the gun cotton does not always proceed harmlessly as in this particular instance. All chemical changes, as I have already reminded you, are attended by the development of heat. Now, if gun cotton be closely packed in boxes containing many pounds each, the heat which is developed can only pass off very slowly, the gun cotton being a bad conductor of heat. Hence

the contents of a package becomes warmer and warmer, until eventually the heat may accumulate sufficiently to lead to spontaneous ignition of the substance. This is what occurred during the early history of gun cotton, and also at later periods. One of the most dreadful of these explosions which occurred with gun cotton was at Faversham, and originated in the spontaneous development of heat in the gun cotton, owing to its imperfect purification. Gun cotton was therefore set aside altogether for a long time in England and France; but in Austria there were two or three men who still believed in the future of gun cotton, and amongst them was an officer in the Austrian artillery—General von Lenk—who had experimented with it on its first discovery. This officer considerably improved the manufacture and purification of gun cotton, and the modifications which he eventually introduced into the mode of applying it to the various purposes for which gunpowder is used were most ingenious, although they did not lead, as was at first expected, to its superseding gunpowder in any one direction.

I have pointed out to you that by sufficiently compressing gun cotton I can stop its burning altogether. I will now show you a few experiments with gun cotton in different mechanical conditions, in order to illustrate the nature of the improvements which were believed in Austria to have been made in its application. Here we have some loosely-spun yarn or roving, which has been converted into gun cotton. Of this piece I have simply twisted one-half a little tighter than the remainder. I hope to show you by this that the tighter twisting of one part has an important effect upon the rapidity with which this cotton will burn in the open air. I shall apply a light to the centre of this train of gun cotton, and it will burn more rapidly towards one end than the other, because it has been less tightly twisted in that direction.

I have some gun-cotton roving here of two different degrees of coarseness, and I want you to observe that in burning it will behave differently, though the same source of heat is applied to both specimens. These two pieces of gun-cotton yarn I will not ignite with flame, as in the first experiments, but by means of a spark. This piece, which is very loosely spun, burns with flame, you see. I light the other piece, and it does not burn as the former piece did, but only appears to smoulder. Perhaps you will say, "How do we know that it is gun cotton?" In order to show you that it really is gun cotton, I will light the other end with a flame, and you see it burns like the other piece did, though, as it is not so thick, it does not produce so large a flame. Now

to what is due this remarkable difference between the two pieces of gun-cotton yarn? They were both lighted in the same way. It is simply due to this, that one kind of cotton is more closely twisted than the other; and the reason why this very trifling difference makes so great a difference in the behaviour of the gun cotton will, I think, soon be evident to you. When we burn gun cotton in the open air we see a bright flash of flame; but if I burn it in such a way as not to allow the gas developed by its explosion to pass away at once, by igniting it in this large glass jar, you will see, if you will be kind enough to watch closely, that there are really two stages in the burning of this gun cotton. We first see the bright flash of flame, and afterwards we see a comparatively pale flickering flame linger in this vessel.

Now, in gun cotton, as in gunpowder, the carbon, as I have told you, is burned by means of the oxygen derived from the nitric acid; but we have not been able to devise any means of introducing into the composition of gun cotton sufficient oxygen to burn the carbon *thoroughly*. If we do not burn the coal in our grates completely we do not obtain the maximum of heat, converting the carbon into the well-known gas carbonic acid—we obtain a partly-burnt product, the inflammable gas called carbonic oxide. In the case of gun cotton, as we cannot introduce enough oxygen to burn the carbon entirely, we produce by its decomposition a quantity of the inflammable gas carbonic oxide. When we set fire to gun cotton in open air, a considerable part of the body of flame produced is due to this gas, which is at once ignited by the flame of the gun cotton, adding to the volume of the flame and promoting the rapidity of burning of the gun cotton. In the case of a lightly twisted yarn, this burning gas insinuates itself amongst the fibres of gun cotton contiguous to the burning part, and thus promotes rapidity of combustion. But if we twist up the gun-cotton yarn so that this gas cannot penetrate between the fibres, but must pass away only in one direction, namely, in a direct line with the burning surface of gun cotton from which it is given off, the gun cotton is no longer, after the first application of heat, maintained at the temperature necessary for its rapid combustion, and the gas, in turn, is not supplied with the heat necessary for its ignition, while, as it escapes, it carries away heat from the burning part of the gun-cotton thread, and thus still further retards the rapidity with which this burning proceeds. A few experiments will illustrate this better than any amount of speaking. Here is a long piece of this comparatively tightly-twisted cotton yarn, and I will set fire to one extremity by means of a flame in the usual way.

But I will first pass it through a perforation which I make in this card. These experiments take a little time preparing, but I think they are much more instructive when prepared in view of the audience, because you see the whole of the proceeding. Having pulled the piece of yarn partly through the perforation of the card, I lay it flat upon this board, inserting the further end into this small tube. I will tell you beforehand what I hope will take place, because the experiment wants watching. When I set fire to the gun cotton by means of the flame it will burn rapidly, but when the flame reaches that part which is passed through the card, I hope that the gun cotton will at once cease to burn with a quick flame, and will then burn on the other side of the card with a very small tongue-like flame; and for this reason, because the flame having to pass through that perforation, the burning gas is prevented, for an instant, from surrounding the burning cotton, and therefore this is not heated to the same extent, and the gas is extinguished; hence the gun cotton passes from quick to slow burning. I allow it to continue to burn in this slow manner into this tube, and I think I shall be able to show you that as it burns slowly in that tube, I shall be able to light the gas which is disengaged and is retained within the tube. There is the gun cotton burning quickly, and there it is burning slowly; and now the gun cotton is burning slowly within the tube and the gas is burning at the opening. I will give you this experiment in another form—a very simple one. Its success will depend upon steadiness of hand. I am going to light this gun cotton, and will try if I cannot brush out the flame of *the gas* with my hand; that is, not extinguish the gun cotton, but make it pass from quick to slow burning.

This is so tempting a subject for experiments that I cannot help giving you various illustrations of it. I take a little piece of *compressed* gun cotton (of which I shall have something further to say directly) and put it inside the lower end of this long open glass tube, which is held in a vertical position. Now I will ask Dr. Roscoe to be so good as to give me that heated iron I used just now. I am going to light this, but to make it burn only slowly, which I can do by touching the upper surface of the confined pellet of gun cotton with the hot rod of iron. Now the gun cotton is burning at the bottom of the tube, and you see I can inflame the gases evolved from it by applying a light to the upper end of the tube. There is a tall pale flame produced, as you see, while the gun cotton itself is burning at the bottom of the tube.

Let me now tell you the bearing of these experiments.

General von Lenk, the Austrian officer, found that if he twisted gun cotton up tightly it burned more slowly than if he had it loosely twisted; so by winding it more or less tightly on reels, such as I have here, he was able to control its burning in the open air to a very considerable extent. He concluded that if it burned comparatively slowly or gradually in the open air it would do the same in a confined space. Here are specimens of the forms in which he proposed to use gun cotton. Here is a cartridge made for artillery purposes, and the cotton is very tightly twisted, so that it may burn slowly. By this arrangement it was expected that we should no longer have that violent action in the gun which precluded the use of gun cotton for artillery purposes. Here it is twisted up in another way, with a hole in the centre. Here is a loose hollow plait, which will allow the gas to permeate readily between the threads of the plait, and thus cause the gun cotton to burn very quickly. I will take a small piece of this plait and show you the contrast in its burning with that firmly-twisted yarn which you saw just now. This will burn, comparatively speaking, moderately, and when its flame reaches the plait you see the latter bursts into flame suddenly with explosive violence. Unfortunately, it proved in practice that Von Lenk's method of arranging gun cotton, in the form of tightly-wound reels or balls, was of no real practical value. When these were confined in a gun there was little or no retardation of the burning, for then the pressure developed by the confinement was always sufficient to bring about a rapid penetration of the burning gas into the centre of the tightly-twisted gun cotton, which, therefore, burned nearly as rapidly as if the gun had been loaded with gun-cotton wool. Moreover, in those forms of gun cotton which were so arranged as to burn most quickly, he did not get over the difficulty that it was necessary to confine the gun cotton very closely, in order to develope its explosive power thoroughly.

The Austrian experiments, however, led to the study of gun cotton being resumed in this country ten years ago, and the result of numerous experiments led to the conclusion that the system of arranging gun cotton which I have described could be advantageously superseded by another plan, which secured a much more thorough and uniform compression of the material. Upon the principle that the more nearly we convert the substance into a thoroughly solid, compact mass, the more thoroughly we must be able to control its action, it was proposed to convert gun cotton into as dense and compact a state as gunpowder.

For this purpose it was necessary to reduce gun cotton to a

very fine state of division. This was done by very simple means, and the new mode of preparation at once led to an important cheapening of the gun cotton. In preparing gun cotton according to the Austrian process it was necessary to use very long staple cotton, which, I need not tell a Manchester audience, is a comparatively very expensive article, in order to obtain the right description of roving. But to obtain gun cotton suitable for conversion into a fine state of division, we were not compelled to use long staple cotton, but were enabled to use the cheapest description of manufactured cotton, namely, common machinery waste. I need hardly tell you that we buy this cotton waste in Manchester at a very low figure indeed as compared with the price of long staple cotton. We found no difficulty in converting cotton waste into gun cotton, by steeping it in the mixed acids at a low temperature, as readily and perfectly as we could long staple cotton. In purifying the gun cotton thus obtained, a variety of improvements in washing were elaborated. The washed gun cotton was then passed through the ordinary machine used to tear up rags and fibres into pulp for paper-making, and in this way it was obtained in the requisite finely-divided condition. Here is gun cotton reduced to this fine state of division; it corresponds exactly to paper pulp, but it is explosive. Here is some dry. I place a little of it upon a plate, and apply a heated iron; you see there is no doubt about its being gun cotton. In this fine state of division it burns very rapidly. Having obtained it in this form we have it in a condition readily convertible, by compression in powerful hydraulic presses, into solid masses of any shape, such as cylinders, triangles, or cubes of any required density or hardness; indeed there is no difficulty in thus converting gun cotton into masses nearly as hard as gunpowder. This process also enabled us to convert gun cotton into the form of paper, and into granulated gun cotton for sporting purposes. Here we have gun-cotton paper, and here are gun-cotton grains.

I may give you other illustrations of the value of this particular way of manufacturing gun cotton. By incorporating the finely-pulped gun cotton with saltpetre and similar salts, we can obtain comparatively cheaper mixtures, which can be compressed like ordinary gun cotton, and a given weight of which will be equal, in explosive force, to the same weight of the pure, more expensive gun cotton. If we want to make gun cotton for the use of small arms less explosive and violent, we may dilute it with common paper pulp. This is a piece of gun-cotton paper used for making sporting cartridges. It burns slowly, because it is mixed with a

certain quantity of ordinary paper pulp. We can also convert it into light cylinders or grains, and impregnate these with paraffin, or indiarubber, or stearine, or even with sugar, as Mr. Punshon does, in order to retard the rapidity of their explosion. In this way gun cotton can be made more controllable for small arm purposes, but we have not yet been able to tame it sufficiently to allow of its being used with any degree of confidence in great guns. The attempts made up to the present time to moderate its action have only been partially successful in the smallest cannon, and there appears no prospect whatever of our taming it sufficiently for use in larger guns.

I have here a diagram representing different kinds of gunpowder now in use, and here are also specimens of the different descriptions used for heavy artillery. Twenty years ago these small grains of powder represented the cannon powder in universal use. Then we began to build larger guns, and after some time this larger-grained powder was introduced as a safer powder to use in such guns. Powder burns rapidly in proportion to the size and density of its grains or masses, and the fine powder was found to act injuriously upon the big guns, although we had then only got up to the 100-pounder Armstrong gun. We considered we had taken a great stride when we passed from that small grain to this larger grain; but rapid progress was made in developing the size of our artillery, and it was found necessary to pass from grains of powder to pellets or pebbles and prisms of powder—that is to say, we converted powder into masses, which burned, comparatively speaking, very slowly when ignited in the air, but which, when ignited in charges of 80 to 120 lbs., still burned very rapidly in the gun, and produced occasionally an unduly violent action, which it was desirable to moderate. We are talking of building very much bigger guns than the 35-ton gun, which requires a charge of powder weighing 120lbs., and we shall therefore want a much tamer powder for those guns. I am consequently pretty certain that, as far as big guns are concerned, gun cotton has no future; but as regards other very important uses, its future is already thoroughly secured. Now, to show you how this has come about, I must endeavour, in the next twenty minutes, to discuss what I regard as the most interesting subjects of this lecture.

Let me call your attention for a minute to this viscous sugar-like substance which is obtained as a secondary product when oils or fats are converted into soap, and to which we give the name of glycerine. Soon after the discovery of gun cotton it was

found by an Italian chemist that when this substance was acted upon by nitric acid, or its mixture with oil of vitriol, it was converted into a powerful and explosive material even more violent than gun cotton, which he called nitro-glycerine. I have a little of this substance here in a safe condition, dissolved in a spirit obtained by the distillation of wood: in this form we can carry it about safely. If I pour it into this water you see there is a cloudiness upon the water, caused by the separation of the nitro-glycerine, in consequence of the spirit becoming diluted. We will allow it to stand there for a short time, when a small quantity of a heavy liquid will collect at the bottom of the vessel. This liquid is the powerful explosive substance called nitro-glycerine. It detonates even more readily than gun cotton if struck; but burns quietly when simply inflamed.

It was a long time before this substance was looked upon otherwise than as a chemical curiosity. But a Swedish engineer, Mr. Nobel, conceived the idea of substituting it for gunpowder, as a more powerful explosive. First of all he mixed it with gunpowder and exploded it in strong vessels, but the action was uncertain. Eventually he hit upon the idea of exploding it by means of a large percussion cap. He imbedded the cap in the centre of the substance, and he found by then detonating the cap he could explode the material violently. Now what holds good in this respect with regard to nitro-glycerine holds good equally with respect to gun cotton. If we place it into close contact with a powerfully detonating substance, such as fulminating mercury, we can by the explosion of the latter develope the violently explosive properties of gun cotton without in any way confining it, provided the latter be in a sufficiently compact compressed form. When we explode a detonating cap or tube in contact with compressed gun cotton, we hit some portion of it a violent blow, which blow suddenly converts the particle of gun cotton surrounding the cap or tube into gas. The force thus developed is transmitted almost instantly to every other particle; and thus the mass may be detonated with extreme velocity, and with the development of its full explosive form, without any confinement whatever. Thus, instead of having to confine our gun cotton in strong shells or boxes, as was formerly the case, we have now only to lay it against the stockade, or place it in a building, quite unconfined, or under a ship, and its explosive property is effectually developed by means of detonation. But this detonation or blow must be of a certain kind. Although we can detonate gun cotton readily by means of fulminating mercury, some other substances which make

as much noise and appear as destructive will not develope the same action, unless used in overwhelming quantities.

I have here two illustrations of the extraordinary effects developed by detonating gun cotton. One diagram represents part of a fortification at Portsmouth, which it was desired to remove. It was a solid mass of masonry, 5ft. to 7ft. thick, and 250ft. long. Inside the gallery we placed 66lbs. of gun cotton, quite loose, against the wall. You see there are a number of loopholes and places of escape for force, and there was a large door at each end, closed in with wrought iron gratings. This gun cotton was detonated by means of a large percussion cap, or tube, and the result of that detonation was the heap of ruins you see represented there. The most curious part of the affair was the effect of the tremendous rush of gas which took place and caused the destruction of the other end of the mass of masonry. This kind of action could not have been attained without gun cotton, or a similarly violent material; and if it had been placed in the centre of the gallery the whole would have been demolished. Here we have another illustration of the explosive effects of gun cotton. It was an experiment tried upon one of the Martello towers put up for the defence of our coast against the French. A charge of 180lbs. of gun cotton was placed upon the floor of this building, the walls of which were 7ft. to 12ft. thick. Upon the ignition of the cotton the tower was transformed into the heap of ruins you see pictured there.

This will give you an idea of the force developed when detonation is applied to gun cotton. I have lately had the curiosity to examine into the rapidity with which this detonation is transmitted or propagated from one mass of gun cotton to another; and this I was enabled to do by the employment of a most ingenious and important instrument, devised by a late officer in the Artillery, Captain Noble, for determining the velocity with which a projectile travels along the bore of a gun. By means of this instrument, called a chronoscope, it was proved that the rate at which a detonation travels from particle to particle of compressed gun cotton, whether the mass be large or small, ranges between 17,000 and 19,000 feet in a second; that is to say, the mean velocity of its detonation is rather more than 200 miles in a minute, which is just the distance from here to London; so that, if we imagine a continuous train load of gun cotton reaching from here to London, the detonation would be transmitted to London in one minute after it had been started here. Now, that is an extraordinary velocity; though it is small as com-

pared with that of electricity, which travels at the rate of about 288,000 miles per second, it is a remarkable speed compared with the velocity of sound, which travels only at the rate of about 1,100 feet per second.

And now I must tell you with regard to this detonation, that it is essential to its successful development that the gun cotton should be in a dense, compact, or compressed condition, so that its particles may be in a position to resist tendency to motion when they are exposed to a blow or concussion. If I hit this piece of gun-cotton wool a single blow on the anvil, I am not able to detonate it, because the force of the blow is greatly expended in causing the loose fibres to move; but when the gun cotton has thus been rendered compact, its detonation by a blow is readily accomplished; consequently the more highly gun cotton is compressed, the more sensitive it is to detonation. Loose gun-cotton wool, or even gun-cotton yarn, very tightly wound, cannot be detonated in the open air by means of even a very powerful detonating cap or fuse, but compressed gun cotton is able to resist the tendency of detonation to break it up mechanically and disperse it; therefore, it is disintegrated chemically or blown into gas. You see, therefore, that this compression of gun cotton has led to very important results.

I must briefly point out to you a few more illustrations of the effects produced by this plan of exploding gun cotton by detonation. Here are some wrought iron plates, one inch thick, which were fractured by detonating four ounces of gun cotton, placed upon the upper surface; and this strong piece of railway-bar was broken, as you see, both across and lengthways, also by the detonation of four ounces of gun cotton. This large cylinder of wood represents a solid mass of iron, with a small perforation in the centre, which was blown in all directions by four ounces of gun cotton just inserted into the perforation.

One important point I should call your attention to with regard to compressed gun cotton—that is, the safety of its manufacture. I told you just now that after we have produced gun cotton from cotton waste—which is a perfectly safe operation—we wash it thoroughly—that is, of course, a safe operation; so is that of reducing it to pulp in the common rag-engine, the gun cotton being there mixed up with many hundred times its volume of water. Then the pulped or finely-chopped material is washed in a very much larger quantity of water, which is a thoroughly safe operation. After that it is pressed at a low power, and is then converted into these compact forms in a very powerful press. When

it comes out of that press the gun cotton is so wet as to be uninflammable, and these pressing operations, with proper machinery, are perfectly safe. You have seen how readily gun cotton burns when a heat, even much below that of a red-hot iron, is applied to it. Now, here I apply a red-hot iron to a disc of the gun cotton, in the damp condition, as we obtain it after it has been pressed, and I think you will admit that, in this condition, it is evidently by no means dangerous. I am boring a hole in it by means of the red-hot iron. You must take my word for it that this is gun cotton; but I am now putting my mark upon it, and as it has become an historical specimen, through having been operated upon in your presence, I shall hand it to my friend, Professor Roscoe, that it may be placed in the museum of Owens College in recollection of this lecture. No doubt he will find, when this disc is dried, that it is very good gun cotton indeed. And now I think you have an indisputable illustration of the safety of wet compressed gun cotton; but I can give you other illustrations of it. Here I have a sort of Chinese puzzle made out of a gun-cotton disc. All these various pieces have been cut out of the entire disc by means of an ordinary circular saw while the gun cotton was wet. Here is a disc of the kind made for holding the detonating fuses in submarine mines. The fuses fit into these holes and are fired by electricity. These perforations are cut into the gun cotton by drilling machines, which rotate at a speed of about one thousand revolutions per minute. So that you see we are able to do almost anything with gun cotton when we have it in this wet condition. Instead of storing our gun cotton in strong magazines surrounded by moats and guarded jealously by sentries, we pack it in the wet state into bins, very much like corn bins, which are lined with pitch inside to prevent the evaporation of the water. We can thus store many tons of gun cotton in ordinary buildings without fear. In order to determine whether wet gun cotton might thus be stored without danger of explosion, even in case of fire, the Government lately had erected two strong buildings and stored in each of them one ton of gun cotton. After filling up these buildings with combustible material this was set fire to. A fierce fire raged in each building for two hours, and the gun cotton all that time was gradually smouldering away—that is to say, as the outer portions of the discs dried a little they burnt away very quietly indeed, as you saw just now when I applied the hot iron to the damp gun cotton, and at the end of the two hours there was nothing left but the walls of the buildings and the iron bars upon which the packages of gun cotton had rested, and which had

become bent by the heat. From the above it is concluded that we may store gun cotton wet with perfect safety, and postpone the drying of it until the dry material is actually required.

Well, I intended giving you much more of the history of gun cotton, but, as is usual with lecturers, the time has slipped by too rapidly. I have endeavoured to make my explanation clear and my experiments successful, hence my time has not reached so far as I had hoped. I must not detain you much longer, but I would like to say a few words more about the force of gun cotton. The effects produced by its detonation, which I described to you just now, were all obtained with *dry* gun cotton. But we have recently found that we can use it in a *wet* condition as an explosive agent, and that, if simple measures be adopted, it is, if anything, rather stronger in this state than if dry. All we want is a small piece of dry gun cotton to give the wet cotton a sufficiently sharp blow to cause detonation, and then, when detonation is once established, it proceeds more rapidly with wet than with dry gun cotton, the reason being that the air spaces in the compressed gun cotton are filled up by water, which is practically incompressible; hence the gun cotton is more solid or compact when wet at the moment it is hit the blow than when dry, and it therefore yields less to the blow, consequently the detonation progresses at the increased rate of 18,000 to 21,000 feet per second, or about 240 miles per minute. If we want to demolish a strong building, all we have to do is to put this wet gun cotton on the floor, and place in contact with it a small piece of dry gun cotton containing the detonating fuse. If we want to use gun cotton to remove a wreck or sunken rock, or to blow up a ship, we can place the charge in a bag, or even in a fishing net, so that the water can penetrate the whole of the cotton. Results have been obtained as violent, as regards destructive force, by gun cotton thus confined as when placed in the strongest cases we could use. I think you will concur with me in the opinion that these results are very remarkable.

Lastly, it has lately been found that detonation of gun cotton, and of other explosives, may be transmitted through considerable distances by very simple means. I did hope to show you an illustration of this—and I have given my friend, Mr. Harrison, a great deal of trouble to prepare a voltaic battery for this purpose—but I really cannot detain you longer. (Much applause.) You give me so much encouragement that I think I must really show you one experiment on the transmission of detonation.

I have here a substance called the fulminate of silver, which I can deal with in a lecture more readily than with gun cotton, because I can produce the desired results with much smaller quantities of it than I should have to use of gun cotton.

If I were to take one of these small discs of gun cotton, weighing about an ounce, and were to place it in one end of a gas-pipe three feet long and one inch and a quarter in diameter, introducing another disc into the other end of the tube, by detonating the one at this end I should also detonate the one at the other extremity of the tube. If I were to attempt to detonate one disc by another at this distance, in the open air, I should utterly fail. It would be necessary to put these discs of gun cotton not more than about half-an-inch apart. I will illustrate the power of a tube to transmit detonation by means of this glass tube three feet long, using, instead of an ounce of gun cotton, only three-fourths of a grain of fulminate of silver, which I insert into one end, placing a similar quantity of the fulminate in the other extremity. By means of this battery I hope to be able to detonate this fulminate of silver, and to show you that the detonation is transmitted from it to the fulminate at the other extremity. [The explosion shattered the tube at both ends.] Here are two similar quantities of the fulminate placed upon a plate of metal only four inches apart; you see that when I detonate one the other heap remains unaffected.

I must now somewhat abruptly conclude this long lecture, thanking you most heartily for the patient attention you have paid me, and expressing the hope that the small and imperfect history I have given you of gun cotton will have sufficed to excite some interest in your minds for a substance which, during the 27 years of its existence, has passed through very many vicissitudes. Received at first with enthusiasm, too much was expected of the ill-matured discovery, and it soon fell into disrepute, only one or two patient workers clinging to it through all evil repute, and not losing faith in its ultimately proving a really serviceable material. Its study being resumed in England ten years ago, at a time when it was being abandoned even by its staunchest friends, the Austrians, its most valuable properties began to be really developed for the first time, and it was rapidly growing into great importance, when the accident at Stowmarket, two years ago, once more shook the general faith in the reliability of the substance as a safe explosive agent. Fortunately the cause of that accident admitted of being most thoroughly investigated and cleared up, and was proved to be in no way connected with any liability to spontaneous

decomposition of the material as now manufactured. Fortunately, also, the two or three who had battled for gun cotton during the few previous years did not lose heart in consequence of this sad accident, and were not deterred from further efforts by shakes of the head and shrugged shoulders, by the "I told you so" of wise friends, the petty malignity of others who chose to constitute themselves foes, or the worse than discouragement where encouragement should have been hoped for. And thus it has come to pass, that in spite of all casualties, all discouragement, and all forebodings to the contrary, gun cotton has now attained an unassailable position as one of the safest and most efficient of explosive agents.

I think you will agree with me that we are taught by this history of gun cotton the very wholesome lesson never to allow ourselves to be deterred by difficulties and adversity, however severe, from steadily pursuing any labour to which we have once devoted ourselves as being worthy of our energies. Even if we fail to realise our anticipations of the immediate value and importance of our work, depend upon it our labour will not have been in vain, but will in time bear lasting fruit, by having contributed to the advancement of knowledge and the development of truth.

And now let me, in conclusion, endeavour to show you the difference between the ordinary burning of gun cotton and its detonation.

Professor Abel then took a disc of gun cotton and set fire to it. The cotton burned a considerable time, with an intense light and considerable heat. This experiment illustrated that gun cotton could be made to burn steadily in open air, and that it was under perfect control. The cotton burned weighed nine ounces. The lecturer remarked that had as many hundredweight been ignited in a heap its burning would most probably have raised some portion rapidly to the heat at which it would explode.

The last experiment consisted in using a small charge (about one-fiftieth part of the weight of the disc) and firing it with a large percussion cap exploded by electricity. The result was what the lecturer termed a "respectable explosion," the concussion being a very sharp one, and a brick, upon which the little charge rested, being shattered by the explosion.

ANIMAL MECHANICS.

A LECTURE, Delivered in the Hulme Town Hall, Manchester, on Wednesday, November 26th, 1873.

BY S. M. BRADLEY, ESQ., F.R.C.S.

THERE is nothing of which we are so justly proud as our mechanical inventions, yet every time a sparrow hops from a house-top we have an illustration of animal mechanics, which both in the construction of the machine and the mechanism of its movements transcends man's mightiest achievements.

Now I purpose this evening taking a single illustration from the rich and wide domain of animal mechanics, but this perhaps the most beautiful, as it is the most complicated, of them all—I mean the flight of a bird. If the phenomenon of flight were a novelty—if we had never seen a bird fly, and were suddenly to see, say, an eagle dart through space from the bosom of the blue empyrean to the level of the green sward, there turn with the rapidity of lightning and soar straight up to the sun again, we should somewhat wonder at the liberties taken with the laws of gravitation, and should try to puzzle out how the thing was done—to find out, in a word, what the animal mechanics were. This is what I hope to find out, with your help, this evening.

Now the first thing we notice about a machine is its shape. Let us then first examine the shape of the bird, and then the nature of the moving power.

The general shape of a bird is something like the shape of a fish; the object being the same in both, namely, to offer as little resistance as possible to the medium—whether it be air or

water—tnrough which the animal has to force its way. But if you look at a bird with the wings spread, you will find that it is more boat-like in its build. All the best flyers are shaped something like a yacht or cutter. You are perhaps familiar, most of you, with such a boat as this, with the old-fashioned lateen sail, common enough on the Mediterranean. Now, if you happen to be on a mountain-top, and see such a boat reflected in the water; or, if—which comes to the same thing—you double it by adding another to the lower part, you will find that the boat is changed into a fair resemblance of a swallow; only the object aimed at—avoiding resistance, and taking advantage of the currents of air—is much more perfectly achieved in the natural than in the artificial machine.

Now, let us turn to the skeleton of the bird and see what special adaptations are met with here for its aërial existence. Let us contrast for this purpose the scaffold upon which man is built with the skeleton of a bird. You will find, if you contrast the two almost superficially, that there is a strong family likeness between them; the same idea evidently runs through the construction of them both. But while they are much alike in their general construction, there are many variations in the details; they are, so to speak, not "like to like, but like in difference." Look, for instance, at the contrasted heads and necks of these two creatures. You find the head of the bird narrow and tapering and the neck very long and flexible as compared with the same parts of man, for these parts have to perform all the functions of hands and arms. Look at the shoulder of the bird. You have here a double joint; an extra bone indeed, which is absent in the skeleton of man, or at least it has dwindled down into the little coracoid process; whilst in the bird these coracoid bones form the chief elements of the shoulder, and are much larger than the little collar bones, or merry-thought, which are placed in front. Then observe how solidly composed is the entire breastwork of the bird. You find in the bird that there is a prominent and strong keel on the breastbone, while the breastbone of man is quite flat. This keel serves a double purpose: it gives increased space to the great muscle which moves the wing, and it also strengthens the bone. If an engineer wants to strengthen an iron plate, he places another piece at right angles to it, forming what is called T iron. Nature has adopted this form in the breastbone of all birds which are capable of flight.

If you contrast the arm-bones of the bird and of man, you will find that bone for bone they correspond; but this upper arm-bone, or humerus, is much longer, and relatively stronger, than the

same bone of man, having to perform more powerful mechanical feats. The bones of the fore arm very closely correspond; but they, too, in the bird, are longer and relatively stronger. If, then, you look at the bones of the wrist and the fingers, you will find that in the bird they are stunted, insignificant affairs, merely having to support certain feathers, and strongly contrast with the wonderful and complex mechanism of the human hand. The same likeness in difference pervades the whole skeleton. If now you take a human bone and cut across it, you will find that it is hollowed out in the interior; and this same construction is carried even further in the bones of the bird; in fact the bone of a bird is a mere hollow cylinder; so that, size for size, the bone of a bird is much lighter than the bone of a man, but weight for weight it is stronger, because the structure is more tightly packed.

Now we find by experiment that the human bone is relatively to weight four times as strong as cast-iron, but the bone of a bird is, weight for weight, six times as strong. This human bone required a weight of nearly 900lbs. to break it, but the bone of a bird of equal calibre sustained a weight of 1,500lbs. before it snapped. If you look further at the cut ends of the bone of a bird you will find that this hollow shaft is crossed by a most beautiful lattice-like arrangement of the structure. Now you all know how architects strengthen roofs by tie-beams, girders, and so forth, and very often you will find that there is a right-angled girder which is connected with a cross-piece, the cross-piece being prevented from yielding by a ring of metal placed between the two. You may see such a construction at Stretford station any day in the roof supporting that notable piece of architecture! Nature has adopted this plan ever since she made the first bone. But in spite of the great strength and density of the bone, it is everywhere porous like blotting-paper, so that it freely admits moisture, by means of which the bone is nourished and lives.

The thickness of the human skull is notorious, but yet it is everywhere transparent; so that it is by no means a difficult thing—as I daresay Mr. Harrison will show us—to see right through a man's skull. [Illustration by means of the electric light and the oxy-hydrogen lantern.]

While Mr. Harrison is preparing for the experiment, I will take this opportunity of expressing my hearty thanks for his continuous and constant aid in this lecture; in fact, whatever element of success it possesses is due to him rather than to me. I wish too to thank Mr. Searson very sincerely for the beautiful diagrams which cover the walls.

What is true of the skull is true of every bone in the body. You have therefore in this bony support [the skeleton of a bird] a structure at once light, freely movable, and of sufficient strength to resist all the ordinary forces which are brought to bear against it. But there is something else very interesting and important in the fact that the bones of birds are hollow. You know what a great quantity of fuel a high-pressure engine burns in a day; and in like manner our bird, which is a very high-pressure engine indeed, consumes a great deal of fuel in the shape of food. The swallow, *e.g.*, will eat its own weight of food in a day; and the cormorant more than rivals the swallow in this respect. Just as the engineer requires a constant supply of fresh air to keep his fire bright and clear, so does the bird need a quantity of air to purify the blood, which is the fuel that heats the muscles to the necessary pitch to perform their work. Now to attain this end the air passes not only into the lungs of the bird, but through them into the general cavity of the body, and even into the interior of the hollow bones; so that the warm blood is exposed on every side to the invigorating oxygen of the air. But even this is not all; for, owing to the fact that these bony cavities are connected with the respiratory or breathing apparatus, the bird can either fill these bones with air or exhaust the air from them, turning its lungs into a condensing or exhausting syringe at pleasure. Owing to this fact a high-flying rapacious bird can empty its bones of air and swoop like a cannon ball upon its prey; but ere it touches the ground it attenuates the air by allowing the air to re-enter the hollow bones, and so averts its otherwise inevitable destruction.

If we glance for one moment at the skeleton of a bird in its entirety you will find that not only is each part admirably adapted to perform its functions, but that each part is perfectly in harmony with every other part, and in a measure necessitates every other part, just as the smallest segment of a circle gives the whole figure; or as many a man in this room could, I daresay, from the piston of an engine build up the entire machine, so to one who has sufficient knowledge the smallest fragments of an animal will enable him to build up the entire organism, and to infer its habits and nature.

Let me try to give you an illustration of what I mean. Here is the beak of an eagle. Now, suppose that this were given to a man who had never seen such a bird, but who knew the general nature and habits of the class, how would he be able to say what was the character of skeleton to which this bill was appended? Well, he would know from its hooked character, that this was

a flesh-eating bird. He would then know from the notch which the upper bill presents that it always killed its prey. He would know that such a beak must be associated with a flattened and tapering form of skull, to offer little resistance to the air; eyes of telescopic brightness would be needed to see; and long, strong, and pointed wings to capture and carry off its prey; for this, he knows, is the best type of wing for a high-flyer. Such wings, he knows, must be associated with a breastbone deeply keeled, and with arm-bones of great strength and length; while the whole of the parts about the shoulder he would be able accurately to draw from the strength of the muscles needed to move the wings. The length of the arm-bone would give him the exact length of the thigh-bone, and the length of the leg; while the hooked talons he would be able to add, because he knows that these are always associated with a hooked beak, as aids in capturing, and even rending the prey. In this way Cuvier, from a single tooth, was able to build up the Anoplotherium so perfectly, that when the remains of the animal were discovered somewhat later, there was nothing to alter in the model of the great Frenchman. By following the same law, Buckland, and Mantel, and Owen—of whom we Lancashire men have good reason for being proud—have restored those "dragons of the slime," familiar to us in the gardens of the Crystal Palace. By following this same law of induction, you can trace out not only the character of the skeleton, but the shape and character of the internal organs, and the general nature of the animal. Of course, the application of this needs caution. I saw lately that in some American scientific assembly a member produced an ancient fragment, from which he began to construct, on the blackboard, a creature of very weird appearance, which, when completed, looked like something between a tomcat and a griffin. However, before the assembly were convinced, another gentleman got up and said he did not think that this was the true conclusion to be drawn from the fragment; he thought, indeed, it would bear another reading, and so set to work, and when he had finished his sketch, instead of a griffin, there was a big brown jug! So that you must not suppose that from my speaking in this light, sketchy way, that it is by any means always easy to follow out these co-relations, for, in fact, every care has to be taken in the process.

Now you find on looking at this upper extremity of the bird that the whole limb is in its action a true lever. The arm of man and the wing of the bird are both levers, and each is a lever of what is called the third kind. Where the power is placed between

the weight and the fulcrum, but nearer the latter than the former, we have a lever in which there is great speed of movement, but in which some power is sacrificed to the attainment of velocity. Now in the case of the bird, the fulcrum, which is ever moving, is the wind concentrated at the tip of the wing, the weight or resistance is the body of the bird, and the moving power is the muscle placed between the two. The arms of a man are moved by a lever of the same kind, as I will try to show you. If you will look at this skeleton you will find that the joint of the shoulder is the fulcrum, the arm itself is the weight, and the power is the muscle inserted between them at the point I now touch. In this instance we have substituted string for muscle, and by contracting or shortening this string you see that the arms are raised, and by pulling in another direction the arms are lowered.

Now the wings of a bird are raised and depressed by a lever of precisely the same kind, but the muscle which depresses the wing is much more powerful than the one which raises it. What is further important for you to remember in regard to this part of our subject is that owing to the double joint, which I spoke of before, the bird can place the upper part of its wing at every imaginable angle to the wind, and so can strike the wind vertically or obliquely, or in any other direction it may wish; the remaining joints of the wing, on the contrary, will only move in one plane. You cannot move them backwards or forwards without breaking the bones; they will only move up and down.

I have spoken from time to time of these movements, and it is important that you should understand how they are effected. It is one of the most important points of the whole subject to thoroughly comprehend the mechanism of these movements. All the movements of animals are effected by the shortening or contraction of muscles, which muscles constitute the *flesh* of animals: it does not matter whether we speak of the wriggle of a snail, the skip of a flea, the ponderous tramp of the elephant, or the flight of a bird, all are effected by the shortening of the component muscles. We put out our tongue—if we should be guilty of such an indiscretion—by muscular contraction, and we draw it back again by an expenditure of the same force. Let us see if we can give you an illustration of this muscular contraction. For this purpose we will take the muscle of a frog and place it in a little slide which is connected with a galvanic battery—for we find that muscles contract to galvanism precisely as they do to the mandate of the will—and you will find that there is muscular

contraction when the circle of the battery is completed. [Experiment.] There is no mistaking the movement you now see. The same action results whenever the same muscle is touched, but when another muscle is contracted another action will result. Now, in the case of the bird the great muscle which depresses the wing occupies the principal part of the breast-bone, and is fixed to the under part of the arm by a strong tendon that you see here. The elevation of the wing, on the contrary, is effected by a very much smaller muscle, which you see above, and which raises the wing with very little trouble, aided, as it is, by these elastic bands or ligaments. The shape of the muscle is interesting and important to notice. The muscle which depresses the wing is somewhat triangular, but in point of fact it is not quite triangular—it is really a skew muscle, which possesses the curious property that while every line is straight all the surfaces are curved. It is the form which geometricians designate as the "hyperboloid of one sheet." Geometricians have been a long time in discovering all the properties of the hyperboloid of one sheet; but nature has been acquainted with the advantage of such a form ever since the first bird was sent forth into the air. Now, you will notice that in this muscle, tapering from its broad origin to its insertion, there must apparently be much less strength at one part than at another; but owing to a peculiar arrangement by which many of the fibres are tucked underneath, there is as much strength at one end of the muscle as at the other. If it were not for such an arrangement the muscle would be torn every time it was forcibly contracted. Now the muscle which raises the wing is of a different shape: you see it in this upper diagram. It is what is called a penniform muscle, and you do not find many of these muscles in the bodies of animals; nature seems chary of the use of this shape; but it is a shape admirably suited to produce great effects with very little expenditure of force. All the fibres radiate at equal distances from a central tendon, and every fibre being equal in length, when they are all put into action at the same time, the muscle becomes for its size a very strong one indeed.

Now I want you to thoroughly understand how the muscles which depress the wing of the bird will move the end of the wing through a much larger space than the muscle itself moves through. For this purpose we will attach a little lever to the end of the muscle, and cause it to contract. [Experiment.] Here is the muscle connected with a galvanic battery; and now, when the circle is completed, you see that this long end of the lever moves through a considerable space, while the muscle itself contracts but very slightly.

Here, you perceive, the power is placed between the fulcrum and the weight moved. These contractions are apparently slight, because the poor frog has been dead some little time; but in the living body they are really made with very considerable force. Professor Donders calculates that each fibre of a muscle (for the muscles are made up of an infinite number of little strings, or fibres), which only measures about one five-hundredth of an inch across, will raise nearly three grains every time it contracts; and we have, further, the high authority of Professor Haughton for stating that, if you had a muscle a square inch in diameter, it would raise 104 lbs. through one foot of space in a minute. So you may readily suppose that the power with which the whole of the pectoral muscle of a bird contracts is very great indeed. I have roughly calculated that the great muscle which moves the wing of an albatross at each stroke contracts with a force of about 30lbs., which you will easily suppose is quite sufficient to keep the noble bird soaring in the higher regions of the air, with unwearied pinion, hour after hour. But, in spite of this great strength of muscle, there is a certain loss of force; and this loss of force is due to the fact that these levers are of the character called intrinsic—they are in the body of the bird itself—are part and parcel of the creature. This always involves a certain loss and waste of force. For instance, the muscle which moves the wing of the wood-pigeon would be capable, according to the muscular coefficient of Professor Haughton, of raising 100lbs. through a foot of space in a minute; but each contraction of the muscle is not so very powerful as this would lead us to suppose. We find, by experiment, that, after chloroforming a pigeon, if you tie a string round the tendon end of the great pectoral muscle and galvanise it, it will be only capable of twitching a weight of about 5lbs.; whereas, if the whole force of the muscle were utilised on external objects, it would be capable of moving a considerably greater weight. Continuing the experiment, a somewhat interesting fact comes out in the difference between the strength of living and dead muscular fibre; for, while the muscle of the living bird will bear a weight of 10lbs. before it breaks, you will find that 8lbs. are sufficient to rupture the same muscle when the life is gone, as evidenced by its no longer responding to galvanism. No putrefactive change has set in; it is simply that the mysterious something which has never yet been defined—and, perhaps, we know not, never may—the *life* is gone. Now, you may suppose from this that Nature is somewhat wasteful in these muscles; but, in point of fact, Nature is very careful. Nature really works here

as elsewhere, on the principle of getting the best return that she can for her outlay, like the thrifty housewife that she is. I will try to make this plain by a rough diagram. [Mr. Bradley illustrated this by a diagram upon the blackboard.] If you take two curves—it does not matter what curves they are—we find that when these two curves lie in the same plane, we can discover by geometry exactly the point round which the muscle should turn the bone which it rotates. There is only one such point, and if the socket of the bird is fixed exactly at that point, Nature has solved the problem, the details of which geometricians have been a long time in discovering. The problem is an intricate one, and might prove uninteresting to you. Suffice it to say that we are able to construct an ellipse upon the bisector of the triangle made by connecting the two curves, and then find the ideal axis of rotation, which in this case would be in the minor axis of the ellipse. Now, Professor Haughton finds that in every case—and he has examined a great many birds—the socket of this bone is placed in the ideal socket which the geometricians tell us is the best point round which to move the wing of the bird if working on the principle of least action.

There is another point I want to mention about muscular contraction. It is this, that the whole of the muscle is never contracted at the same time; there would be great exhaustion following its long-continued contraction if it were so; but the contraction passes along in a wave-like manner from point to point. You may calculate the rate at which this contraction takes place, for we find that muscles in contracting give out a peculiar musical note, something like the blowing of machinery, with which you are familiar, or like the rattling of a distant cab over a stony street. This note is called the "susurrus." You may try the experiment for yourselves. If you rest your elbows on a table, stop your ears with your fingers, and work your jaws to and fro (it doesn't matter whether you have anything between them or not), you will immediately hear a sort of blowing murmur. That is due to the contraction of your "masseters," or chewing muscles, passing from point to point. Now the tone or pitch of every note depends on the number of its vibrations; the higher the note the more numerous the vibrations—the lower or more base the note the fewer the vibrations. This curious note which the muscle gives out is synonymous with what musicians tells us is C below the stave in the bass clef, which we know is caused by 32 vibrations per second. It follows from this that every time a muscle acts the whole mass undergoes this alternate contraction and

relaxation 32 times in a second, which doubtless affords time, short though it be, for the whole mass to rest and recruit itself; literally "in its very motion there is rest."

You have seen that action, or contraction, always results when galvanism is applied. You will probably ask, What then represents this galvanism in nature? What is the natural battery? What intelligently governs the movements of the wing? We have a rough outline of the machine to be moved; we have a rough outline of the moving power; but where is the engineer who intelligently guides and controls those movements? The engineer is the brain, placed in the skull, like a "little cherub that sits up aloft" to take care of the life of poor dickey; and the communication between the driver and the machine is effected by little white threads, called nerves.

Now, if we take our muscle once more, but instead of directly applying galvanism to it, apply galvanism to the nerves which pass into it, you will find that it contracts exactly as it does when the galvanism is applied directly to the muscle itself; and, when the electricity is applied to it in a very forcible manner, you will find that the contraction is correspondingly considerable. This experiment may give you an idea of what we call nervous tone. You know that when a man strings up his nervous energy by means of his will, that his strength of muscle is increased. The electricity is now traversing this muscle which is thereby contracted, and you perceive when the current is increased the contraction is carried farther, until, in this case, the connection between the muscle and the battery is ruptured. [Experiment.]

Now, both muscles and nerves possess the property of evolving electricity just like that battery, so that we have good reason for supposing that the muscles in the human body respond to precisely the same stimulus that they do when removed from the body. It is quite true that electricity travels very much quicker than nervous force does. The mandate which your brain gives out to your arm to move is not by any means so quick as an electric current flashing along the wires. Electricity travels, indeed, about two million times quicker than nerve force, but this may perhaps be explained by the fact that the nerve force has to pass through an infinite number of little albuminous cells, each of which little cells partially stops or inhibits the current. If it were not for this nerve force might perhaps travel as quickly as electricity.

Neither the microscope nor chemistry discovers any difference between one kind of nerve and another; and yet we know, from

their mode of action, that there are two quite distinct kinds—the function of the one being to carry messages from the muscles to the brain, and the duty of the other to convey the mandate from the brain to the muscles: both are essential to the proper working of the wing. For instance, if the sensory fibres, as those are called which carry messages from the muscles to the brain, are cut, though the wing may move, it does so in a purposeless sort of way, and the result is that it churns the air, but does not advance by flight. If, on the other hand, the motor fibres are cut, as those are called which convey messages from the brain to the muscles, although the poor bird may know what movements are required, it cannot execute them; the brain and muscles may be intact, but the telegraphic wires connecting the two are gone. Both these muscular and nervous actions are instances of what are called "forces;" and it is a very interesting fact, that these forces are perfectly indestructible; they are mutually interchangeable, but they are indestructible—constituting a mutable, but, at the same time, an immortal force. The electricity which is evolved by the nerve produces a certain quantity of heat in the muscle, which, in its turn, produces certain definite chemical changes; and these are again re-convertible into precisely the same quantity of electricity. The light and heat of this electric lamp are only other phases of electricity. So that the same science which teaches the wonderful properties of matter, proclaims at the same time the eternity of force, of which our lives and the workings of our brains are but other manifestations; thus it is but natural, if you will permit me to stray into the realms of poetry, to say—

> That the faire lampe, from whose celestial ray
> The light proceeds, shall never perish or decay;
> For when its vital spirits do expire
> Upon its native planet shall retire—
> For it is heavenlie borne and cannot die,
> Being a parcell of the purest skie.

Every time a nerve or muscle acts, we have a discharge of electricity, and the rapidity with which these nervous and muscular batteries are charged and discharged is something marvellous.

An ingenious French physician, M. Marey, has lately shown how we can calculate the rapidity of the wing-strokes of birds, by noting the rapidity of the electrical discharges. The heron, which is one of the laziest flyers, makes 150 strokes of the wing per minute; but that is nothing to such a bird as the hawk, which attains a speed of 150 miles in an hour. In making these calculations, M. Marey appends to the arm-bones of the bird two thin wires, which are connected with a galvanic battery. He then

allows the bird to fly freely about the room. To the battery end of one of the wires there is attached a little pencil, and every time the bird moves its wing it breaks the current, which current is immediately re-made, and the fact recorded by the movement of the pencil on a moving screen. The movements, like the waves of a sphygmographic tracing—which instrument, by-the-bye, is the invention of the same man—are easily counted, and in this way he has tabulated the rapidity of wing-stroke of many birds. He finds, *e.g.*, the wild duck moves its wing 9 times a second, or 540 times a minute. The sparrow, which is, I believe, the most rapid wing-beater of all, makes 13 strokes in a second, or 780 times in a minute; and this, too, without fatigue!

Let us now turn to the mechanism of the beautiful body clothing, the feathers of birds, and then look to the mechanics of the wing itself, and of flight. Now, every feather—it does not matter whence we take it—is composed of the same elements or parts; namely, a central part, "the quill," or "barrel," and the "vane," or "beard," which is in its turn composed of "barbs," as they are called, placed, like the teeth of a comb, side by side, and of little hooks called "barbules," which pass at right angles from each margin of the flat surface of the barb and pot-hook into each other, keeping the whole feather perfectly airtight and efficient for raising the bird. You will find that every feather is composed of these same parts. If you take a feather and separate the barbs slowly, you find that they cling together somewhat; and this is due to the interlocking of these little hooks, or "barbules." If you try the experiment of blowing air through a feather you will find it a somewhat difficult task. If you with a blowpipe blow air upon a feather, you will find it passes from one side to the other; but not a breath passes through the feather. The whole instrument is utilised to strike the air and raise the bird.

The lightness of feathers is proverbial, but their strength is quite as remarkable. This feather has this afternoon borne a weight of ten pounds without yielding in the least degree, and the barbs and barbules are also marvellously strong for their size. All feathers are formed like hair, and nail, and teeth, from the deeper layers of the skin; in fact, hair and feathers are almost identical in their mode of growth; but there are certain differences in their properties, which are rather interesting. You will find, for instance, that while water and damp will soften hair, and if placed in a Papin's digester will even dissolve it, it will have no effect on feathers. Thus the moisture in this room will, I fear, take the curl out of the ladies' fairest tresses, but it will have no effect

whatever upon their pretty plumes of feathers, excepting those of the ostrich, and such birds as do not fly. Water will make ostrich feathers limp, but it has no effect whatever upon the feathers of birds of flight, else every sparrow would be in a sorry condition after a passing shower. This is due to the fact that feathers are composed almost entirely of a substance like white of egg—albumen, which even long-continued boiling does not affect, and to the existence of microscopic sluices in the bars and barbules, along which the water trickles without penetrating the feather in the slightest degree.

If you now glance at the feathers of a bird generally you will, of course, find them to be of different shape and size in different parts of the body, and these different shapes and sizes generally indicate that they subserve different functions. If you refer to this albatross you will see that the body feathers answer the purpose of increasing the bulk of the bird, and thus by increasing the space exposed to the air they lighten the body of the bird, and at the same time keep the body warm, which is a very important thing, when a few minutes is sufficient to bring a bird down from the region of perpetual snow to the tropical regions of the valleys. For this same reason the body covering of little birds is tinted black, because black is the colour which best retains heat. The feathers of other parts again perform different functions. Thus, for instance, the feathers of the tail are the principal means by which the bird steers, the feathers of the wing being, of course, the main agents of flight. The gorgeous tail feathers of the bird of paradise and the peacock, the Elizabethan ruffles of the coot, and the feathery crest of the crowned crane, are more for ornament than use, and are somewhat ungallantly borne as a rule by the male portion only of the class.

It is somewhat curious to notice that birds with long legs never have long tails. The fact is, that when a bird has long legs it carries them behind it when flying, and so does not need a tail-rudder at all.

The wing feathers of birds are of three classes: there are the long feathers, which are fixed to the fingers; then there are the feathers which are fixed to the further end of the forearm; and the feathers which are fixed to the body end of the forearm. These feathers, which have received special names, decrease in size while they increase in number. [These facts were illustrated by the aid of diagrams and specimens.] The long feathers attached to the fingers are the primary feathers; the others, more numerous but smaller, are called respectively secondaries and

tertiaries. It is owing to their general arrangement that the whole wing is somewhat triangular, the base of the triangle being placed at the attached or body end of the pinion. If it were not so, if the triangle were reversed, the muscles would have to be immensely more powerful, and therefore more bulky than would be compatible with an aërial existence. Nevertheless, it is quite true that if it were possible to reverse this triangle without adding to the weight of muscle, it would be even a more efficient agent of flight than it is under existing circumstances; because the further and longer end of the wing would move through a greater area of space, and so would inflict a more efficient stroke upon the yielding air. Do we find such a shape in nature? Yes, I think we do in the wings of insects. You will find that the light wings of insects are triangular, but the apex of the triangle is the fixed end, the broad base forming the free circumference. Let us throw some of these wings of insects on the screen, and you will see that the shape is as I describe. It is owing to this arrangement that the flight of insects is, proportionately to their size, so marvellously rapid. A dragon fly will fly more swiftly than a swallow, and is a still more perfect aërial waltzer. But this could not be managed, in spite of the great strength of insect muscles, if the entire gossamer wings were not almost as light as air itself. That is the general shape of the wing, but there are other things to be noticed about the mechanical properties of the feathers which are not a little interesting. If you look at a feather you will find that the vane extends on both sides of the quill or barrel, but on one side you see it extends further than on the other. The shorter side serves simply, by union with the neighbouring one, to keep the wing as one entire sheet, and so leaves the broad side free to scythe-like smite the air. If you look at a feather with the flat surface towards you, you will see that it is somewhat oval, but if you turn the edge of the feather level with your eye, the whole feather being held edgeways, you will find, curiously enough, that the feather is slightly curved upon itself, forming a sort of figure-of-eight loop. It is, in point of fact, shaped exactly like the blade of an Archimedean screw propeller, the object being the same in both. By means of this curvilinear shape the bird would be able to ascend in the air, even if it were to beat the air horizontally, as I can show you by a simple toy. This little toy has its blades shaped like the feathers of a bird, or like the blades of a screw propeller. Now, if these blades are made to rotate horizontally very rapidly you will see that it soars

into the air. It does not matter how you throw it. Here is one made with the blades curved in the reverse direction, which I must throw down to enable it to rise—"it stoops to conquer." Now you will readily understand that the feather of a bird is a much better instrument for this purpose than the blade of a screw, because it not only strikes the air in the same effective fashion, but in its recoil it avoids the retarding influence of the back current, which in the case of the screw propeller is one of the greatest difficulties to be contended with, and one, indeed, which we have never yet been able to overcome in human mechanics. Not only does each feather strike the air in this effective fashion, but the whole wing is thus screwed down upon the air, and in its recoil unscrews itself; and this, together with the curving manner in which the wing is unfolded and folded, combined with the varying angles which it makes with the body of the bird, gives, as Pettigrew was the first to point out, first a figure of 8, and then a waved track to the flight of a bird. If you look again at the wing in its entirety you will notice that it is hollow underneath and rounded above. Every wing will show you this shape. You may see the same in a lady's parasol, which is rounded above and hollow beneath; and if you move it up and down you will find out the object served by this shape, for you will at once observe that it is much easier to raise it than to depress it; it moves up without any resistance, but it requires some force to bring it down, because air collects underneath. So that, in point of fact, you have a double object served in this round shape. Not only does it grip the air in its down stroke, and avoid it in its up stroke, but in its down stroke, when it is falling, the air collects beneath and raises it to a position for a fresh down stroke. You may observe this in the hopping flight of the sparrow, which is a perpetual succession of ups and downs in the world, only the ups vastly preponderate over the downs, as I hope they do in most of our lives.

There is another point to be noticed in the construction of the wing of a bird. Here is the model of a wing, to show the property I am speaking of now. If you look at this wing you will see that each feather overlaps its neighbour, like the tiles of a house overlap one another, and the consequence of this is that during the down stroke the feathers are kept perfectly tight, one over the other, and the whole wing is used as an effective agent in raising the bird; but in the up stroke you see that the feathers become separated from each other, and the air filters through them without let or hindrance, the whole object clearly being to

render the up stroke as little injurious, so to speak; in retarding, and the down stroke as effective as possible in continuing, the onward and upward course of the bird. But you will notice another fact which this model serves very well to show, viz., that the front part of the wing is very stiff, while at the hind part of the wing the feathers are quite unsupported. It is owing to this that when the wing strikes the wind vertically, the tips of these feathers are tilted upwards, and this tilting up tends to move the wing along horizontally; thus mere vertical flapping of the wings is not sufficient to enable a bird to soar—it will rather carry it straight forward; but when the bird flies perpendicularly upwards it strikes somewhat obliquely downwards and forwards. If you take the wing of any large bird and try to bring it down quite vertically, you will find you cannot do so; it will move along in spite of you, because of this tilting up of the hinder part of the feathers. I have here a small apparatus made of paper which illustrates, I think, this mechanical fact to which I have referred. [Experiment.] Thus you will understand that a great deal of the flight of birds is purely mechanical—it is not effected by any expenditure of force; and whenever Nature can produce an effect with little expenditure of force she always does so. If you watch the circling flight of pigeons you will find that after a few rapid strokes of their wings, they will sail along in the most charming fashion without the slightest expenditure of any exertion, as though they floated on the wind, without the aid of their wings, by the sole act of their will; just as you may see the skater skim along the ice, after a few rapid strokes, for an incredible distance. Now whether a bird launches itself from a height or rises directly from the ground, gravitation is always, of course, acting against the upward tendency of the wing-strokes, and yet without gravitation, paradoxical as it sounds, the bird could not fly. The elements necessary to flight are gravitation and the resistance of the air, both apparent impediments. The pressure of the air, however, in a great measure counteracts gravitation; further, the wings are outspread so as to offer the maximum of resistance to the air perpendicularly, and the minimum of resistance to the air horizontally. The stroke of the wing, which I have tried to describe to you, tends to raise the bird by the elastic rebound of the air; gravitation tends to pull the bird down to the earth: the consequence is, that the wing must overcome gravitation, and, having accomplished this, the bird can pursue either an upward, a horizontal, or a downward course, by altering the angle at which the wing strikes the wind. I ought to

add, that the centre of gravity is always placed very far forward in birds of flight, which is manifestly the most favourable situation. You see in these diagrams the attitude of the wing in horizontal, vertical, and oblique flight. In making a rapid descent the bird raises its wings above its head and falls plumb-like, the wind offering scarcely any impediment to the descent of the bird when the wings are raised, like clasped hands, above the head. But the most difficult feat of all is *standing* in the air; and yet you will find that standing perfectly stationary in the air is a feat that is sometimes practised by birds. You may, for instance, see a kite, when a breeze is blowing (for it is only possible then), as stationary as Simon Stylites on his pillar, watching for his prey. You will find that when the bird is thus stationary the wind impinges against the body of the bird at an angle, and tends to push the bird upwards and forwards; gravitation, of course, is tending to pull it down. Then the kite balances the two by a most perfect adjustment of the angles made by tail and wings to the air, the tail being held fan-like, the wings raised higher than the horizontal lines, and so stands in the air—like a boy's kite, the string being gravitation—watching for its quarry, and at the same time witching the world with noble wingmanship. Of course, the shape of wings varies with the powers of flight; but all, I think, may be classed in one of two great groups—the round wing and the pointed wing. The round wing is the possession of the ground flyers; the pointed wing the property of the high flyers. The round wing is sometimes possessed by birds like the partridge, which fly quickly, and when this is the case they always make a great whirr in passing through the air, owing to the broad surface which strikes the wind; "el wiz," for this reason, is the name, in Arabic, for wild duck. But the pointed wing is the peculiar possession of birds of lofty flight. Sometimes special provision is made to enable them to cut their way through their airy path without noise, as in the case of the owl, which beneath the wings possesses a cover of down, so that in the night it can quite noiselessly pursue its prey, and pounce upon frog or mouse without the risk of disturbing those somewhat watchful animals.

I should like, for the few minutes that remain at our disposal, to glance at one or two types of these wings; and first, let us glance at a specimen of the rounded wing. The rounded wing in its most simple form is never possessed by birds which soar into the atmosphere, but is the property of birds which are more or less terrestrial or aquatic in their habits

Now there is, perhaps, no bird in which the first feeble

flutterings of the wing are better seen than in the penguin. Here we have a group of these somewhat Puritan-looking penguins. If you look at their wings you will find that they are stunted and paddle-like more than wing-like; and yet, in spite of this, you find the arrangement of the bones, and the primary, secondary, and tertiary feathers just as in the lordly albatross. The penguin cannot fly, the wing not being sufficiently developed to enable it to raise the heavy body into the air; but it can strike the water with its wings, and so contrives to scud along the surface of the sea with considerable speed.

Now, let us contrast this round wing with a wing of a totally different type, that of the swallow. What can be a greater contrast than the paddle of the penguin and the sharp-pointed wing of the swallow, a perfect bird of prey, killing its thousand insects and more per day, but at the same time a true scavenger and purifier of the air? That is the typical wing of the high flyer. You never see such a tail as that associated with poor powers of flight or with long legs. Let us turn to another pointed wing, that of the beautiful skylark, as we see him here leaving the dull earth to sing hymns at "heaven's gate;" or let us turn to another specimen of a splendid flyer, for there are good and bad flyers as there are good and bad pianists. The muscles of the wing require educating just as do the muscles of the fingers in the pianist or violinist. Here is a splendid flyer, the lammermeyer, the eagle of the Alps, which sweeps along the crags with its narrow, scythe-like wings, flying high above the loftiest peaks, along regions never touched by human foot, or reached by the sound of the human voice. Or, let us turn to the most beautiful of all the birds of flight, closely akin to our albatross, the frigate-bird, as we see him here descending from his home in the blue sky to his home on the blue water. Glorious proprietor of every element—of air, of sea, and of land! He takes his pastime in the air, makes his nest upon the land, and finds his cradle on the deep. In such birds as this frigate-bird, which can both dive and fly, the wings are almost ribbon-like, so as to enable them to act as oars *beneath* the water. These birds have always much difficulty in rising, and often have to rise *against* the wind, but once up remain in the air with very little movement of the wing.

One of the earliest science lecturers of whom we have any record, Aristotle, once asked what the condition of a man would be who had been brought up to maturity in darkness, who should be suddenly brought into the bright light of day. How the sounds and sights of nature would thrill, astonish, and delight him!

Carlyle, speaking of such a man, says:—

> Nature would be to this man what to the thinker and prophet it ever is—*preternatural.* This green, flowery, rock-built earth, the trees, the mountains, rivers, many-sounding seas; that great deep sea of azure that swims overhead; the winds sweeping through it, the black cloud fashioning itself together, now pouring out fire, now hail and rain. What is it? Ay, what? At bottom we do not yet know; we can never know at all. It is not by our superior insight that we escape the difficulty; it is by our superior levity, our inattention, our *want* of insight. It is *not* by thinking that we cease to wonder at it. Hardened round us, encasing wholly every notion we form, is a wrappage of traditions, hearsays, mere *words.* We call that fire of the black thunder cloud "electricity," and lecture learnedly about it, and grind the like of it out of glass and silk; but *what* is it? Whence comes it? Whither goes it? Science has done much for us; but it is a poor science that would hide from us the great deep sacred infinitude of Nescience, whither we can now penetrate, on which all science swims as a mere superficial film. This world, after all our science and sciences, is still a miracle; wonderful, inscrutable, *magical,* and more, to whosoever will think of it.

Here, then, with the descent of the bird, we, as it were, arrest our brief flight. No one knows better than I do how lame the pinion is upon which we have attempted to fly with you to-night. But I am content if my poor words have sufficed to arouse in you some interest in the subject of Nature's mechanics. Do not dream for a moment that Nature is rifled of all her treasures. This very realm of animal mechanics on which we have touched to-night, with so light hand, is as yet an almost untrodden region. It is for you to lay bare the treasures of the country, and to annex it to the great kingdom of science. Nature allows no room for Alexanders to weep that there are no fresh fields to conquer, for Nature is inexhaustible, and will remain so. Every fresh height gained in science serves but to reveal peaks of greater magnitude beyond. It is only in these latter days that we have, as we now imagine, perfected certain mechanical inventions; but even these have been before us in the human body, and in the bodies of other animals, from the beginning of time. In the arches of the human foot we have construction which eclipse in their beauty and mechanical properties such mere passive weight-carriers as the bridges of Stephenson or of Brunel. The locomotive is present in the human body, but unlike the boasted invention of man, which wastes some 90 per cent of its fuel, it utilises every fraction of heat. The electric telegraph too is there, but I think the battery of the brain and the dial of the hand somewhat overshadow man's achievement. Still we are proud, not without reason, of what we have done, for it is by following Nature. We shall never advance our knowledge of any natural law by attempting to unravel her secrets in an unnatural manner. In this very subject which we have been considering to-night, it is not by neglecting the first principle of flight—which is always to have a body heavier than air—it is not by miserable balloon experiments that we shall ever "climb the

spheery clime;" but if we are to fly it will be by humbly following Nature and learning what she has to teach. There is no study so certainly rewarded as this pursuit of Nature. He who courts her honestly, patiently, earnestly, she will by no means send empty away. As an old Roman said, it is well when we can mix the pleasant with the useful and the good; and, in the study of Nature, this must be ever so; for her ways, like Wisdom's, are "ways of pleasantness, and all her paths are peace."

THE SENSES.

A LECTURE, Delivered in the Hulme Town Hall, Manchester, on Wednesday, December 3rd, 1873.

BY PROFESSOR CROOM ROBERTSON, M.A.

SUPPOSE, by a wild stretch of imagination, some mechanism that will make a rod turn round one of its ends, quite slowly at first, but then faster and faster, till it will revolve any number of times in a second; which is, of course, perfectly imaginable, though you could not find such a rod or put together such a mechanism. Let the whirling go on in a dark room, and suppose a man there knowing nothing of the rod: how will he be affected by it? So long as it turns but a few times in the second, he will not be affected at all unless he is near enough to receive a blow on the skin. But as soon as it begins to spin from sixteen to twenty times a second, a deep growling note will break in upon him through his ear; and as the rate then grows swifter, the tone will go on becoming less and less grave, and soon more and more acute, till it will reach a pitch of shrillness hardly to be borne, when the speed has to be counted by tens of thousands. At length, about the stage of forty thousand revolutions a second, more or less, the shrillness will pass into stillness; silence will again reign as at the first, nor any more be broken. The rod might now plunge on in mad fury for a very long time without making any difference to the man; but let it suddenly come to whirl some million times a second, and then through intervening space faint rays of heat will begin to steal towards him, setting up a feeling of warmth in his skin; which again will grow more and more intense, as now through tens and hundreds and thousands of millions the rate of revolution is supposed to

rise. Why not billions? The heat at first will be only so much the greater. But, lo! about the stage of four hundred billions there is more—a dim red light becomes visible in the gloom; and now, while the rate still mounts up, the heat in its turn dies away, till it vanishes as the sound vanished; but the red light will have passed for the eye into a yellow, a green, a blue, and, last of all, a violet. And to the violet, the revolutions being now about eight hundred billions a second, there will succeed darkness—night, as in the beginning. This darkness too, like the stillness, will never more be broken. Let the rod whirl on as it may, its doings cannot come within the ken of that man's senses.

This experimental fancy—rather apt to take the breath away—I quote from the German books where it is to be found, because it brings into line, in a striking way, the most of what physical science can tell us about the senses, and at the same time suggests a number of questions, which, though they go beyond physics to answer, are among those that we must try to deal with this evening. Physics, as you know, is the science treating of nature, or the world of matter; and it explains what it can of the changes or processes going on there by resolving them into motions, under some general laws that have been very certainly determined. Now a great part of all the changes in nature are in the sensible qualities of things, such as their colour, temperature, and the like; and for all the variety of these the physical inquirer seeks out an expression in terms of motion. That in the objects sound, colour, &c., are motions, however they may appear to particular senses, was long ago surmised; as, indeed, in the case of sound, which first began to be understood, the fact is often quite evident. Sonorous bodies like a bell or a drum or a musical string are plainly in motion, which may pass to other bodies, and in particular by one great body, the air, can be carried a long way. The motion in bodies when giving forth light or heat, and the medium—not air—which is the general bearer of that motion, have been much less easy to determine; but modern inquiry has practically mastered the difficulty, and the tremendous figures given in our fancied experiment are some of those assigned in all soberness for the number of vibrations per second in the all-pervading ether that go with simple sensations of heat and colour in us. There is no expression of the same definite kind for tastes and smells; the process there being of the chemical rather than of the mechanical sort. But a chemical action also is, in the last resort, intelligible to us only as a mode of motion; and thus we may say that all sensible qualities are resolved by physical

science into motions in the objects. In touch, which has not been mentioned, the action is mechanical of the most apparent kind.

Now, coming back to our rod, whose whirling is supposed to communicate to the air and ether in the room motions of like rate to those caused in fact by sounding, hot and shining bodies, we may remark two things strange. The first is that its motion had no effect on the man except at particular stages, and within a definite range at each. Putting always aside the case of actual contact as practically out of the question, we note the blank before the first deep groan burst forth, the tremendous blank when the last screech had gone out until heat began to steal in, and again the immeasurable tract lying beyond the limit where light passed into darkness. The second fact is that within a certain range the motion appeared differently as both heat and light. Why should one rate of the motion appear only as sound, another only as heat, and another only as light? Why should other rates among or outside of these not appear as anything at all? And why should one rate appear doubly as both heat and light? These are questions that do not concern the physical inquirer, whose work is done when he has got the sensible qualities into expressions admitting of definite measurement. But we must try to find an answer for them.

There can be no doubt in what direction we have first to look. The question is why bodies outside of us affect us in certain ways and not in others. Well, of course, that depends on our capacity of being affected. Our physical frame or body offers itself to be acted on by other bodies in motion, and the result in the first instance must depend upon what organs and what kind of organs it has for receiving the motion or stimulus. This it is the business of a different man of science, the physiologist, to determine; and within the last generation or two—not earlier—a great deal has been done for the physiology of sensation, however much remains to be learned.

In regular sensation, as of a colour or sound, there is an invisible disturbance in some part or parts of the mass of the brain within the skull. This disturbance results from an ingoing wave or current of invisible motion along the white fibrous lines called nerves. This wave or current begins at the outer ends of the nerve-fibres, where they are in conjunction with various microscopic structures, partly nervous, partly other than nervous; and these structures are reached by the exciting stimulus (which we have seen to be some motion, visible or invisible, in external bodies), through the parts or openings on the surface of the human body—eyes, ears, and the like—which are commonly called the organs of

the senses. It is a very complex process altogether, and for true sensation all the stages are of account; yet some are easily seen to be of greater importance than others. Least important is the part played by the external organs, for these are often injured without sensation being stopped. Most important is the action of the brain, without which there can be no conscious state at all. For the rest, let us carefully distinguish between the nerve-fibres going to the brain and their endings in the minute structures. Nerve-fibres, by themselves, are mere conductors which, like telegraph-wires, may carry indifferently in either direction, and, though in the actual nerves, which are compound bundles of fibres, they carry only one way, they will carry any sort of disturbance, whatever it be, that is strong enough to rouse them at all. Thus the optic nerve may be excited by any strong pressure, and is not excited when acted on directly by the proper stimulus of light, which happens to be a very weak one. In short, the fibrous lines of nerve seem not to determine the character of the sensations had through them, any more than a telegraph-wire determines the import of the message sent along it. But, if the mere nerves are practically alike in structure and function, most varied is the structure of their endings at the outer organs. The endings in ear, and eye, and skin are quite different; and, again, at different parts of the same organ—as between the middle and sides of the back of the eye, or between the finger-tips, and skin of the shoulders in the organ of touch—the variety of structure is very great. Note this second point, because we shall come back upon it later. It is the first point that concerns us now.

Besides the fibres, it should be observed that the nervous system includes another sort of matter, consisting of darker-coloured cells, extremely minute in size. These cells, wherever found—in little gatherings here and there, or compacted into a column at the heart of the spinal cord, or massed variously at the base of the brain, or packed away in the winding folds next to the skull-cap—are storehouses of pent-up energy, ready, upon the least excitement, to burst forth as invisible motion along fibrous lines laid from them. The fibres are in substance much less unstable, and, besides, both singly and as done up in bundles, or again in the sets of bundles which are called nerves, are protected by sheaths along their whole length, the ends only being left exposed. Now, as the brain buried away in the skull is, in the regular process of sensation, thrown into action only by the disturbance sent up along the nerve-fibres from their tiny ends thus unprotected, the stimulus applied here must either be very strong in itself, or, it

weak, must somehow be strengthened to produce an effect. And strong enough it sometimes is, as from a violent blow or burn on the skin, destroying the very tissue of the nerves where they end, and thence, by way of the spinal cord and brain, throwing the whole frame into convulsive spasms. More commonly however the natural stimulus, as we had already occasion to remark of light, is very weak. What strength, do you suppose, is there in those inconceivably minute ether-waves that reach us after travelling years and years through space from a glimmering star of the sixth magnitude? Or what violence is there in the air-waves bringing tidings that a pin has fallen on the floor? Unless there is some means of intensifying or multiplying the stimulus, it will tap in vain even where the sluggish fibres present open ends to it. Now, practically, there are such means. Specks of the grey unstable matter are found at many places joined with the fibre-ends, able to catch stimulus too faint to be of any avail against the lazy indifference of these. It is as if an anxious inmate of a house, eager to learn news of some event, but unable to stir abroad, and distrustful of the porter at the door, should keep on the watch outside a small boy of his own flesh and blood, eager like himself, who should arouse the sleepy doorkeeper on every the least occasion. Other structures also are found in the eye, that seem to make the signal more marked by first changing its character. In the ear there are various devices increasing the effect on the nerve-filaments. Under the skin, wherever touch is delicate, hard little bodies are disposed, doing regularly for the fibre-ends what happens when a thorn finds its way there. To give you any idea of the delicacy and variety of the arrangements is here impossible, not to say that much still remains to be learnt; but there is this broad fact to be taken along with us—that the regular stimulation from natural agents, often a most gentle motion, is taken up at all by our nerves only when it has first been variously modified at the points where these stand exposed.

Let us now recall the questions forced upon us by the rod-experiment. First, there was that strange fact of breaks or blanks in sensation, with perfect continuity of physical stimulation. May we not say now that a great deal of stimulation can easily be lost upon us for want of proper means to take it up by the nerves? It is a question, at least at the first stage, of mere physical correspondence. You strike a string in one piano, and a string in another close by begins also to vibrate, while other strings remain quite still. So the nervous system, through the nerve-endings, responds with action of its own to some rates or kinds of physical motion, and does not respond to ether-vibrations above those of

violet and below those of heat, or air-vibrations outside a certain range; because the eye, and the skin, and the ear. in those essential parts of them through which the nerve-fibres are affected, are constituted not otherwise than they are. Thus also may we account for the different sensibility of different people. Some hear sounds at both ends of the scale that average ears never take in; and others, with ears of less than ordinary compass, never hear a bat squeak or a cricket chirp. The like is true of vision, and the common fact of colour-blindness, blotting out for so many people some colours entirely, is now ascribed to the absence of certain of the minute elements in the retina or sensitive curtain at the back of the eye. And what is total deafness or blindness? This may be due to defect in the central organ of the brain, but also, though centres are intact and the nervous communication is perfect, let the truly sensitive parts in ear or eye be only a little changed, and then, while air or ether may surge and eddy as before, the clefts that were in consciousness will have become chasms, engulphing the sensible glory of the world.

The other question was how the same physical stimulus could at the same time be the occasion of sensations so different as heat and light. Well, but what a difference of organ there is at the skin and in the eye! If there is any meaning at all in speaking of bodily conditions for mental states, it is impossible not to connect with the difference of the minute structures under the skin and at the back of the eye both the fact that at the extremes of the whole sensible range ether-waves are caught up by one line which are not caught up by the other, and also the fact that within a certain mean range the same waves are caught up differently towards a different conscious result. See what takes place in another organ—the tongue. Through the tongue, at its tip, we not only taste, but also have a finer sense of touch than even in the fingers, and the curious thing is that the double duty is there done by a single nerve—not different nerves, as for heat and light. How can the same nerve, say from the same lump of sugar, take on impressions so different as sweetness and roughness? Perhaps the microscope tells when it tracks part of the fine nerve-filaments to little structures known from the analogy of the tactile organs elsewhere to be serviceable for touch, and part into little cup-shaped openings, which are most probably the nerve-endings for taste, since we know that in order to be tasted substances must first be brought to the state of liquid solution. After that the case of heat and light, where the organs are so very

cannot at least be thought strange. The skin within itself

presents still another instance of double sensibility, contact and temperature, which some would make treble by adding (in my opinion erroneously) a sense of pain. Whether it is here enough to suppose the nerve-endings the same and only the mode of stimulation, as it in fact is, different; or whether there must be supposed peculiar nerve-endings for each sensibility, are questions to be decided by positive evidence when it can be got.

It may now occur to some of you as not so difficult, from this point of view, to conceive of a great increase in our sensible experience, by merely supposing us to have other organs, or the present organs slightly varied, for catching up the stimulation that plainly is lost upon us. Why should our senses be limited to five, or some such number? Voltaire, in one of his tales, has a humorous fancy of people in Saturn with seventy-two senses, visited by a wanderer from the region of the Dog-star with the decent outfit of a thousand. Why not? Under our own eyes do we not see the lower animals often acting in a way that means, if not quite other senses than ours, at least senses of quite another range? But we must not stray into questions of that sort, when there are others pressing more to be answered. For, now that we have taken from physiology a rough notion of what happens in the human body, as before we took from physics a rough notion of what happens in external bodies, when there is sensation, we are still rather at the beginning than the end of our inquiry. Colour, for instance, which appears to be in bodies but is not there except as a dance of particles, which is had only through the eye and brain but is not there except as a current and explosion—is what in itself? And if not in the thing called coloured except in appearance, why does it so appear? Neither physics nor physiology can tell, but only, if at all, the science of mind, which is called psychology. I say "if at all," because even the psychologist will tell us what sensation is not, rather than what it is. This, however, is not surprising, for neither does the science of physics tell what motion is, but only takes it as a fact and discovers its laws. If this is all that can be done for something so evident as motion, much more may we expect it of a mental process like sensation, that cannot in the same way be made evident. The psychologist can search out and classify the kinds of sensations, can show many of them to be much less simple than they at first appear, and can discover the laws according to which they combine to ever new results. It is before the fact of sensation itself that his science, like all others, breaks down. There is nothing simpler to express it by. It is sometimes said

that sensations are signs in consciousness of events that are constantly occurring in the material world; but though this saying has a good meaning and is true, it makes nothing plainer. The difficulty turns up again in the word consciousness. In fact, we are here face to face with the great mystery of our being, and must bow the head. The psychologist tries rather to comprehend how sensations, with other elements of conscious experience, conspire towards the inexpressibly varied result of our full mental life. Now sensations enter chiefly into our apprehension of the vast material universe stretching away on all sides from us, and the main question as regards them is how that can be?

Let us take the question in the simpler form that occurred to us before. Colours and the like, which are not in things nor in the brain, but in the mind or consciousness, appear to us all to be in the things. Why? It is no sufficient answer to say that as there is nothing but sensations in the mind—no direct apprehension of motions in the objects or organs—the mind can put into objects nothing else. Why is anything put outside at all? I cannot hope to give anything like a full answer to the question even in the simplest form; but some things may be said that have an important bearing on it, and that should in any case be stated in giving an account of the senses.

First of all observe that by no means all sensations are put outside of us into things. Besides the sensations of the five senses we have a great many other simple feelings, often called bodily feelings, and best spoken of under the general name of Organic Sensations, because they are connected with the action, healthy or diseased, of the vital organs. Of these none are referred to external objects in the way that colours or sounds are, and only some of them, like suffocation and hunger, are referred to particular seats in the body. Even in the five senses many states are hardly referred beyond the organs through which they arise. Tastes seem to us in the tongue; smells, often in the nostrils, sounds, not seldom in the ear. So also in touch the pain of a cut from a knife appears to us in the skin, and in sight the sensation of dazzling light is rather within the eye than without. The regular sensations of sight and touch are, however, referred outside. Colours always seem as if spread out in space, and distinct points of light appear to stand apart. The sensation of smoothness and hardness from the same knife that caused pain in the skin, seem to us no states of ours but qualities of the blade. And less regularly sounds also and odours appear to come as if from things.

Observe next this other series of facts. While it is generally

true of all these sensations that we are passive under them, meaning that in certain circumstances it does not depend upon our will whether we have them or not, there is yet a great difference among them, when they are present, in respect of our power to control them. We often have sensations which no action can modify whatever we do: whether we run, walk, stand, or lie, the discomfort continues, and all we can say is that it is "somewhere inside." Other sensations of the organic sort, less vague, and referred to particular seats, as the lungs, or stomach, or teeth, we do have some control over: by general pressure on the parts, or other local applications, we may often alter their degree. Greater, though still limited, is our control over states referred to the organs of special sense: though we cannot at once get rid of pains like those of a cut, or a burn, or a bitter taste in the mouth, we can act very directly to modify them. We can altogether get rid of the smells and sounds that are referred to external things—if not by merely turning the head, closing the passages with the fingers or otherwise, then, at the worst, by getting up and moving bodily away. Most perfect by far, however, is the control over touches and sights. Here there is an action or motion of the organs themselves. What so easily moved as the eye and hand? We can vary or discard touches and sights at will by simply moving the organs.

What may we make out from the two sets of facts thus running by the side of each other? In proportion as sensations are beyond the control of our active movements, they appear or remain with us as mere sensations. In proportion as they appear to be qualities of things, and cease to appear as sensations, they are subject to such control. Till some other element of difference be assigned, it is open to say that the absence or presence of active movement with them makes all the difference. That is not, however, the proper way to put it. It is a difference in our consciousness or mental experience that has to be accounted for, and the fact of active movement is nothing to the purpose if we are not conscious of it. But this is just what we are. Though I have before expressly kept it out of view, there is, by the side of all these sensations, another kind of simple conscious experience—the sense of activity put forth, now commonly called the Muscular Sense. In some respects it is like other sensation, and in some respects very different. It is like in being a simple experience, that is, one that cannot be brought to anything simpler, and also in being connected physically with the action of nerves. It is different in being the consciousness of active exertion, not of any affection passively received, and also on the physical side, because

there is reason to believe that it arises in or with the fact of motor impulse being sent out from the brain by the nervous lines going to the muscles, not, like sensation proper, in connection with nervous disturbance at the surface, which is passed up to the brain. The experience is had in or with all movements that we consciously make through our members, in every case of bodily strain (where our movement is resisted or impeded), in weighing things with our hands, in running over things with the eyes. Bodies as spread out in space and resisting penetration there, also the space we call free between bodies, cannot be apprehended without it. To see this, just watch the movements of a child making the acquaintance of new objects or a new place. I do not say more, because I do not wish to take you beyond the region of facts on to ground that has been disputed among philosophers for ages. It is too hard a question to venture on here, how sensations, when blended with our conscious experience of activity, may come to be transformed into the guise of sensible qualities in things. But we may look a little more closely at the two chief senses—touch and sight—that give us a perception of things as external.

We have already seen how touch and sight stand apart from the other senses, and there is still more to say on that head. However we may project outside of us the sensations of sound, or smell, or even taste, it is always into things already supposed tangible or visible, or both tangible and visible. Our world may be called one of sights and touches. An object spoken of comes before the mind first as it would look to the eye, if seen, or to the touch, if felt. This is true even of things that powerfully affect other senses, and have their value accordingly; for example, a piece of sugar, a rose, a bell. As I uttered those words, did not a representation of certain visible and tangible forms first rise before you, one bearing sweetness, another fragrance, and the third sound, either in fact or as a possibility. Now, why? The first remark to make is that, as a fact, all objects perceived by us do, or may, affect sight and touch, while by no means all affect the other senses. Most objects give forth no sound that ever is heard, no odour that ever is smelt, nor ever fail to be tasted. Though it may be, in the first two cases, only because our hearing and smell are not fine enough—though it may be quite different in many of the lower animals—the fact remains true of human beings. Remark next that smells and sounds (we may drop tastes as unimportant) generally, as it were, steal in upon us, without calling for any action on our part to

become sensible of them; and, again, that there is a great deal of active movement on our part that brings on no smells or sounds. On the other hand, observe how, in touching and seeing, we are in general actively moving the hands and eyes; and, what is still more remarkable, that practically we never move either the body in general, or those most mobile parts of it, the arms and hands and the eyes, as we constantly are doing, without experiencing a variety of sensations of touch and sight. I say in these circumstances it is impossible, if it be true that bodies in space are apprehended through our muscular activity—it is impossible that their other prominent qualities, besides extension and resistance, should not be supplied by touch and sight.

But is it the case that we do not touch or see without moving our hands and eyes? By touch, with my hand at rest, I perceive this table spread out and hard; by sight I perceive this hall, and in it people, with eyes kept perfectly still. True, I had to move my hand into contact with the table, and my eyelids to open them; also, touching this table for the first time in the dark, I certainly should move my hand over it to know what it was, as still I must move my eyes about to take in hall and people properly. It is the fact, nevertheless, that the mere outspread hand tells of an object spread out in space, and the mere open eye discloses a vast variety of objects.

The fact appears quite fatal to our view, and yet I venture to assert that there is no stronger confirmation of it, the organs of touch and vision being what they are. With different parts of the skin we touch quite differently, and see differently with different parts of the retina. Touch is best at the tip of the tongue and tips of the fingers, also in the hand generally. Sight is best within a small area known as the yellow spot, near the middle of the back of the eye. As the retina comes forward round the inside of the eye, it grows less sensitive; likewise on the skin there is a falling-off away from the hand, greatest, perhaps, on the back. The differences depend physically on the number of nerve-filaments going to the parts, and on the kind of nerve-endings found there, both (as we remarked before of the latter) varying greatly; but let that pass. In our mental experience the differences appear as some variety of quality or kind in the sensations. Thus an object bright-red, when held straight before the eye fixed, loses in brightness and even in colour as it is moved sideways; still more an unfamiliar object, first seen with the side of the eye, has a different look when it comes to be seen through the yellow spot in the middle. So a piece of cloth feels quite differently to the back and

to the fingers. There is another and very striking way of bringing out the difference in touch. Two points of a compass felt as double at some parts seem one at others, and the differences as measured are most surprising. The tip of the tongue feels them double if only they are $\frac{1}{24}$ inch apart, and the tip of the fore-finger if only $\frac{1}{12}$; but they must be held from two to three inches apart at the back and other places, or they will be felt as one point only. Hence the notion has been started that the skin should be viewed as a sort of mosaic, made up of little areas or plots of varying size—very small and closely packed at the sensitive places, and comparatively large elsewhere—each having its own quality of touch, not the same as at any other. Though the view has never yet been stated in a perfectly unexceptionable way, the idea conveyed as to the varying quality of the sensations is, I consider, substantially correct. Whenever two touches are distinguished, it must be because of some difference between them in consciousness; and the only difference that can be at bottom is of the kind called quality. We distinguish tastes by their quality, smells by their quality, sounds by their quality; and the different quality of musical sounds is now believed to depend on the different nerve-fibres affected. Why not also in touch, where there may be a difference, not of nerve-fibres only, but of nerves? I hold that in many cases we do actually feel the difference of quality, and that where we do not it is because the difference comes, as we shall see, to mean something else. In the eye there is no doubt about the fact, for there the difference of quality remains apparent.

If the difference is a fact, there must first be some means of discounting it in practice, whenever confusion might arise from the varying reports. The means consists in taking as a standard the report of that part of the whole organ which is at once most sensitive and most easily moved. For touch this is the hand and especially the finger-tips, the more sensitive tongue being not fit for general work; for the eye it is the yellow spot about the middle. The hand may truly be called *the* organ of touch, to which the rest of the skin plays a part like that of the web about a spider: let there be a suggestion of contact anywhere, and straightway the hand can be borne thither, to feel for itself. So in the eye: no spider darts from its lair in the centre to any part of its web more deftly than the yellow spot turns round, with the swift and easy motion of the eyeball, to catch for itself the images thrown on other parts of the retina. The yellow spot can with like reason be called *the* organ of sight. Nothing is easier than the movement in either case, and accordingly it is often made

when we fancy both hand and eye at rest; nay, it is very difficult, in touching or looking, not to make some movement of the organs. We come, however, not to need to make an actual movement in order to correct roughly the report of any outlying part. Because the differences in the quality of sensation all over the skin and eye are constant at each part, we learn by long experience to judge well enough for many practical purposes what the standard report would be without moving to get it. We still move hand and eye when we want to be quite sure.

Mark now what farther happens in touch. The discrepancies, though got over as elements of confusion by translation into touch of the hand, remain at the different places constant marks of the respective movements necessary to bring the hand thither. Indirectly, also, two different touches will come to suggest the movement of hand necessary to pass from the one place to the other. That is to say, upon the theory of perception which I am here assuming, each kind of touch comes to be localised directly with reference to touch of the hand, and all indirectly come to be localised with reference to each other. The skin is thus again mapped out, and now in the true sense of a map, with every touch in a certain relative position. And so predominant does this new character become in consciousness, that, when now we have touches, we are apt to think of them first as lying apart in their places on the surface of the body, not as they may differ in quality among themselves. The change of character will not seem so wonderful, if we think how in the first months of our lives we were doing little else but feeling about over our bodies with the hands. Its own skin is the first surface that a child comes to know of as spread out in space, and, being itself everywhere sensitive, the skin becomes the direct measure of all surfaces in contact with it. Accordingly, when it is affected at different points, or over a certain extent, we at once perceive a number of objects, or one continuous object, spread out in a manner corresponding. For a rough and general apprehension of that sort there need be no actual movement now; but how much was there not in the past for that to have become possible!

So much for touch. The same does not happen in the eye, because sight itself has to be brought into relation with touch. Sight appears, indeed, to have nothing to do with touch when it opens up far horizons over the face of earth, and even brings within ken the great vault of heaven; but that is not the work of the eye alone. The ever-changing image on the back of the eye, though it imitates upside down, as far as a tiny flat picture can, all

the variety of the great world, gives but a varied suggestion of the experiences to be had from moving up to objects and feeling them—an exact suggestion of objects in a room or on the earth which we can so touch, but a very crude and false suggestion, however beautiful a one, of the star-sown depths of space so utterly beyond our reach. For all its range and delicacy, the eye is but as a servant bringing spoil within the hand's rough grasp; and only has this compensation, that the mind, so to speak, the master of both, sets the acquisition after all to the servant's account. Wherefore, we speak of simply *seeing* objects, and we do, in fact, spread over their full dimensions, as apprehended by the moving hand, or imagined upon a corresponding scale, the colour which is the note of the eye's service. Now, because the eye, in spite of this recognition of its work, does not determine what we call the real size, shape, distance, and other such attributes of objects, but only supplies varied marks thereof, we are not to expect that the differences of quality in the sensibility of the retina should among themselves appear in such a new character as that acquired by those of touch. Without ceasing to be mere differences in kind of light and colour, they can each in that character become suggestive signs of such general movements of body as will bring about active contact with the objects. And thus with my eyes simply open and fixed, the mere gradations of optical effect, as determined by the structure of the retina, suffice to suggest to me such general apprehensions of a hall with people in it as I thus get. It becomes a more distinct apprehension when I throw my eyes about and bring part after part of the retinal picture on the spot of clearest vision; but even so, what the eye does is still only to give a suggestion, though a better-marked one, of the experiences I should have in detail, if I were to walk about in the hall and feel over successively the various objects it contains.

I have thus tried to bring before you some aspects of a very great subject. How can there be a greater than the Senses, when here we have nothing less than the two worlds of matter and mind brought manifestly together? Though the subject could only be touched on the surface here and there, I may have given you matter for a good deal of thought. And if there were any need to draw a moral, it might be this, that as the firmest apprehensions and convictions, like those we have just been considering, may emerge from the slow growth of daily experience, we cannot be too careful, where we have things in our power, what we suffer our daily experience to be.

MUSCLE AND NERVE.

A LECTURE, Delivered in the Hulme Town Hall, Manchester, on Wednesday, December 10th, 1873.

By PROFESSOR ARTHUR GAMGEE, M.D., F.R.S.

MOVEMENTS are so characteristic of animal life that I scarcely need to apologise for having chosen the subject of "Muscle" for this evening's lecture, for I intend to-night to draw your attention almost exclusively to those structures which occur in the animal body, and which confer upon it, or upon the parts of which it is composed, the power of moving. I shall only cursorily direct your attention to nerves; yet, as it is impossible to treat muscle without considering nerve, I have allowed the title of this lecture to be "Muscle and Nerve."

I have said that movement is decidedly characteristic of animal life. However lowly the creatures which we study, we find that they invariably accomplish, during life, certain movements. The little shapeless mass of jelly which is known as the Amaeba is, for instance, capable of undergoing changes in shape. It has the power of throwing out processes and of drawing them in again, and, in this way, of moving. Now these movements are due to the peculiar property which the soft jelly-like matter of which it is composed possesses, of shortening and elongating—that property which we denominate *contractility*. As we ascend the animal scale, we find this property possessed by structures of higher complexity, and in the higher animals by a class of structures which we denominate the muscles, which are the active agents in effecting movements.

The movements which we perform can be arranged in two groups. We have *voluntary* and *involuntary* movements. You all know that you can execute certain movements whenever you

wish to execute them. You *will* to raise a certain object from the ground, and calling into action certain muscles you are able to effect your purpose; the act follows as a direct consequence of your having willed that it should take place, and generally you are perfectly conscious of the act having been performed; nay, more, if the object which you have lifted has been a heavy one, you are made acquainted by peculiar sensations with the effort which has been expended in the act. On the other hand, most complicated movements are constantly going on within us which are in no way dependent upon our wills. You know quite well that when you fall asleep, although voluntary movements cease, your heart continues to beat, and the movements of respiration continue to recur as regularly as during your waking hours. These are instances of the movements which are constantly going on within us quite independently of our wills. Our life would indeed be insecure if the delicate mechanism, whose constant action is essential to its continuance, were placed under the control of our own frail wills!

The two different kinds of movements—the voluntary and the involuntary—are effected by muscles of different structures.

Let us first consider voluntary muscles. As an example of a voluntary muscle, I shall take the powerful *biceps*—the muscle which is much concerned in flexing the forearm upon the shoulder. If you look at this structure as it has been somewhat rudely delineated in this diagram, you will observe that it possesses a red colour. You are all acquainted with the appearance of muscle, seeing that the flesh which forms so large a part of our food is composed almost entirely of muscle. You observe that this red fleshy mass—the biceps—is attached to certain bones; above, it is connected by two so-called *tendons* to the shoulder blade, and below, by another tendon to one of the two bones of the forearm; viz., to the *radius*.

This muscle is, as we can discover by a mere naked-eye examination, covered by a pretty strong sheath, formed of connective tissue—a tissue which is very widely distributed throughout the body, and which serves to bind together the various organs of which it is composed, and to connect the individual anatomical elements which enter into the composition of each organ. This external sheath which covers the muscle sends processes into the fleshy mass, which surround the various bundles into which its substance can be divided.

If we take one of the larger bundles of muscular substance and tear it asunder by the aid of needles, we can break it into smaller

and smaller bundles, until at last we arrive at the smallest bundles. These small bundles can only be examined by the aid of the microscope. They are composed of a large number of so-called muscular fibres enclosed in a sheath of connective tissue. If you look at the diagram to which I am now pointing you will observe that these muscular fibres are marked by transverse *striæ* or stripes, hence voluntary muscle is often spoken of as *striped muscle*, and the fibres of which it is composed as *striped fibres*.

The smallest bundles of muscular fibres are of very great length; they usually extend from one end of a muscle to the other—from its point of origin in one bone to its point of insertion in another; the individual muscular fibres are, however, not so long, each measuring, roughly, about an inch and a half.

Now it is the ultimate muscular fibres of which each small bundle is made up which constitute the essential part of a muscle; it is owing to the power which each fibre possesses of shortening, that muscles as a whole are capable of drawing together the structures with which they are connected; and it is, therefore, essential that we should study the characters of the ultimate muscular fibre. The contractile matter which forms the bulk of each fibre is contained within a very delicate and highly elastic sheath, which is termed the *sarcolemma;* this sheath is so delicate and so transparent that it can only be shown under peculiar circumstances. When we employ high powers in the investigation of the structure of muscular fibre we observe an alternation of dark and light spaces, which give rise to the appearance of transverse striæ, or stripes, to which I have already referred.

It would be quite out of place here to enter at length upon the very disputed questions relating to the structure of striped muscular fibre. I shall merely say that a muscular fibre appears to be made up by the super-position of a series of discs, which are separated one from another by a substance which possesses different optical properties from, and which is more fluid than, the matter composing the discs. Of the actual structure of the discs I shall say nothing.

If from voluntary we pass to involuntary muscles we are at once struck by the difference in their physical appearance and in their arrangement. *As a rule* the involuntary muscles are *pale* in colour, not red, and they present no transverse markings or striæ—they are *smooth* or *unstriped.*

These involuntary muscles do not connect bones together, but are generally found arranged in thin layers around hollow organs; we can split up the layers in which they are arranged into bundles,

and these bundles are seen to be composed of spindle-shaped cells, arranged side by side, and of which I show you various forms in the diagram to which I now point. You will be able to form some idea of the arrangement of involuntary muscular fibres by studying a diagram in which I have had represented the three layers of muscular fibres which enter into the composition of the walls of the stomach, and which enable this organ to execute its peculiar and complicated movements. You will observe a longitudinal set of fibres running from one end of the organ to the other; then an oblique set of fibres, and then a set of circular fibres.

I stated that involuntary muscles are pale and unstriped, contrasting with voluntary muscles, which are red and striped; there is, however, a great exception to this rule.

The heart is made up of muscular fibres which are red and which are striped; these fibres are not, however, identical with those of voluntary muscle, for they do not possess the highly elastic and transparent *sarcolemma*, or sheath; and, in addition, they communicate one with the other by processes.

Although it does not properly belong to this part of my lecture, I wish an experiment to be now performed, which I should defer were I not afraid that delay would be fatal to its success.

Before the commencement of this lecture I removed the heart from a frog, which had previously been killed by decapitation, and I placed it in an arrangement which will enable me, by means of the magic lantern, to project its image on a screen.

Although the animal from which this heart was removed has been dead for some time, the heart still continues to live and to exhibit the movements which were characteristic of the organ during life.

Though emptied of blood, though separated from the blood-vessels with which it was connected, you will observe that the little organ alternately contracts and dilates, the movements succeeding one another in a rhythmical manner, *i.e.*, at regular intervals.

If you watch closely you will observe that the auricles contract distinctly before this, the ventricle—that not only the movements of the heart as a whole proceed very much as they did when that organ still formed a part of the body, but that the movements of the constituent parts of the heart likewise follow in the order which was their characteristic during life. The heart which you now see beating affords to you an illustration of the fact that involuntary as well as voluntary muscular fibre possesses in a typical

manner the property of contractility. Unlike the voluntary muscles, which we shall chiefly study this evening, the heart possesses within itself a nervous mechanism which permits it, independently of the central organs of the nervous system, to contract and to dilate.

As we are in the act of observing the movements of the little heart, we notice that they become slower and slower, more and more sluggish; exposure to the heat of the lantern is killing the muscular fibres, and their death is necessarily followed by a cessation of the contractility which is the attribute of living, as distinguished from dead, muscle.

But I must return to voluntary muscles. Every muscle is capable of existing in two states, viz., of repose and of activity. When a muscle is in the first condition, or that of repose, it is elongated; when in the second, or that of activity, it is contracted. From the first, or passive, condition, the muscle passes into the second on the application of various stimuli or irritants. These may act directly on the muscular substance, or indirectly through the nerves which are distributed to it. By far the most powerful stimuli to the contraction of muscle are the influences which travel to them along nerves from the nerve-centres, or the influence (change) which we induce in a nerve going to a muscle by exciting it in various manners. If we isolate the nerve going to a muscle and subject it to a succession of little blows, each blow will originate changes in the nerve, which, being propagated to the muscle, induce contraction. If the blows follow one another with only a moderate rapidity, the muscle shortens, and immediately thereafter becomes elongated; whilst if the blows follow one another with great rapidity, say forty or fifty times in a second, the muscle is shortened and remains shortened during the whole time that the nerve is excited by the blows. Instead of exciting the nerve by blows we might employ electricity. If, for example, we pass a single induction shock through a nerve, we shall produce a single muscular contraction; if we pass a series of rapidly succeeding shocks we observe the persistent form of contraction, such as is produced by a succession of blows. By bringing heated bodies near a nerve, or some chemical compounds, as solution of common salt, in contact with a nerve, we can similarly induce contraction in the muscle or muscles to which it is distributed.

To demonstrate to you the relations which exist between muscle and nerve I shall perform an experiment which will, I hope, illustrate many points of great interest. I have here the

thigh bone of a frog recently killed by decapitation; the thigh bone has been cut across so as to admit of its being fixed into the clamp of the little apparatus which is on the table before me, and which is known as a *muscle-telegraph*. To the bone is still attached the gastrocnemius muscle, which has been separated from its connections with the leg and foot. Attached to the muscle you will observe a little white cord, which is the sciatic nerve—the large nerve which runs down the back of the thigh and which supplies the gastrocnemius muscle.

You will observe that, having clamped the thigh bone, I fix the tendon of the little muscle to a hook which is attached to a silken cord. This cord passes over a little pulley, and is so attached, at the other extremity, that anything which will cause the muscle to shorten will lift up a round red disc (made of painted mica). I now take the nerve and place it in contact with two platinum wires connected with an induction coil. I have other wires, which establish a communication between the muscle and the coil. By an arrangement, which I cannot describe to you in detail, I can now at will excite the nerve either by one or by a series of induction shocks, or I can send the shocks through the muscle or through the nerve.

I am now exciting the nerve, and you observe that the red disc is raised. I now excite the muscle directly, without interfering with the nerve, and the disc is again raised—the raising indicating that the muscle became shortened as a result of the excitation. I am now passing, at long intervals, single induction shocks, alternately through muscle and nerve, and you observe that, as a result, the red disc is lifted up for a very short space of time, falling down again immediately. As a result of these single excitations we have produced *single muscular contractions*. Now, however, I send a series of shocks through the nerve, and you observe that the red disc is raised, but does not fall—indicating that the muscle remains contracted as long as the induction shocks pass. We have by these successive shocks produced the form of muscular contraction which we call tetanus, and which is of interest to us as it resembles the normal form of contraction of our muscles when they are thrown into action by an exercise of the will.

The tissues upon which we are experimenting are still alive. They will, however, soon die—though at unequal rates. The nerve will die first, and then the muscle. After a few minutes of exposure to the atmosphere of this room, this little nerve will cease to bring about contraction of the muscle with which it is connected, when the nerve is excited by the various means which

I have mentioned. After the nerve has lost its properties of bringing about muscular contraction, the muscle itself will be contractile on the direct application of a stimulus to it. Sooner or later, however, the muscle will lose its contractility, and we shall then say that it is dead.

The fact that muscular contractility persists, after death of the nerve, supplying a muscle, is a proof that contractility is a property of the muscular substance, and is quite independent of the nerves; and another proof is to be found in the fact that the muscles continue contractile after we have paralysed those motor nerves which are distributed to them. Thus the arrow poison known as "woorara" paralyses the animals subjected to its influence by a special action which it exerts on the terminations of the motor nerves in muscle. It can be shown that under these circumstances the contractility of muscle persists long after excitation of nerves has ceased to bring about any change in their form.

Now that you are acquainted with the fact that contractility is a property inherent in muscle, and that, in virtue of it, muscles possess the power of contraction on the application of various stimuli, either to the muscular substance directly, or to the nerves which supply it, I wish to give you some idea of the methods which physiologists have employed and do employ in the accurate study of muscular contraction.

What methods have been devised for ascertaining, for instance, that a single muscular contraction occupies about 30-hundredths of a second—that an interval somewhat shorter than 2-hundredths of a second generally intervenes between the time of the application of the stimulus to the muscle and the commencement of its contraction—that the shortening of a muscle occupies less time than its elongation?

I shall attempt to convey to you some knowledge of the methods which furnish us with accurate information on these points. I now show you a small apparatus which may be employed in these researches. We have here a clamp, into which is fixed the thigh-bone of a frog. Those who are sufficiently near will observe that to this femur is attached the little muscle (the gastrocnemius) which served in a previous experiment. The lower end of the muscle communicates by a silk thread with a light lever of wood, the free end of which bears a short point made of glass. The sciatic nerve is laid over two platinum wires, through which a current of electricity may be transmitted. The lever to which the small muscle is connected is now hori-

zontal; whenever the muscle shortens it will, however, raise the lever, which will fall to its original position when the muscle returns to its original state. If we place the point of the lever in contact with a cylinder covered with white paper, whose surface has been blackened (by holding it in a smoky flame), and if we cause the cylinder to rotate by clock-work, a horizontal white line will be traced by the glass point as long as the lever preserves its horizontal position. On causing the muscle to contract, the lever being tilted up, its sharp point will trace upon the rotating cylinder a curve which will represent the changes in the length of the muscle during the period of revolution. If we induce, for instance, a single muscular contraction, the point of the lever leaves the horizontal line which it has traced, to return to it after elongation. If we measure the distance which intervenes between the point where the scratching first leaves the horizontal line, and the point where it returns to it, and if we know the rate of revolution of the cylinder on which these marks are recorded, we can easily determine the length of time which has been occupied by the contraction. It is somewhat difficult to secure an absolutely uniform and constant rate of rotation in a cylinder moved by clock-work, and it is therefore important to have some means of determining the rate of speed at any time. Tuning forks are employed for this purpose. I show you on this table a large tuning fork which, when struck, emits a rather low note; each limb of this fork, when struck, executes 100 vibrations in one second, and these vibrations or movements may be easily recorded on a blackened cylinder, such as is used in experiments on muscular contraction. For this purpose a thin and flexible little tongue of brass is screwed to one limb of the fork. When I strike the fork the little tongue participates in its movements, and if pressed against this blackened and rapidly-revolving cylinder, there are produced a series of very perfect curves, which I shall have the opportunity of projecting on the screen by means of the magic lantern. Each curve was traced in the one-hundredth part of a second. Now if the tuning fork is made to vibrate, and to record its movements on a rotating cylinder, whilst some other act is being recorded by another writing point on the same cylinder, we shall be able to find out the duration of the act by counting the number of tuning fork curves which occurred during its performance.

I shall now project upon the screen two tracings, taken by the methods which I have described. The first illustrates the curves which we obtain when a muscle performs a single contraction and

communicates its movements to a lever. [Dr. Gamgee pointed out at some length how such tracings can be interpreted; he drew special attention to the methods of determining the duration of a contraction, the length of the latent period, and the relative duration of contraction and elongation.] The second tracing, to which I now point, does not, like the first, exhibit a succession of curves of equal magnitude. We observe that the point which traced the line appears pretty suddenly to have ascended to a great height, and then, according to the number of the excitations which the nerve was subjected to, a large number of extremely minute curves, situated almost on a level with the upper part of the first curve, were recorded. I now point to a part of the tracing where the writing-point traced a continuous, unbroken line; indicating that the contracted muscle no longer underwent changes in length which were capable of producing marked curves. This is what we observe when a muscle is tetanised by excitations which follow one another a very large number of times in a second. The unbroken line would continue to be traced at the same height until the excitations were arrested, or until the muscle, becoming exhausted, would be incapable of supporting the weight of the writing lever to its original height.

Now, what are the conditions which are necessary in order that muscular contractility should continue to exist in a muscle? Can a muscle be made to contract indefinitely? I have already anticipated these questions in so far as muscles separated from the living body are concerned, for I have told you that after a shorter or longer time they die. Even when forming a part of the living body, muscles, however, cease to contract if they are too frequently stimulated. You know quite well that if you exert any one muscle for a long period of time, by causing it to repeat very frequently the same act, you very soon feel a sense of fatigue, which will be very much influenced by the amount of actual work which the muscle has performed. Were you to continue to work after the feeling of fatigue had become excessive, you would for the time lose all power of causing the muscle to contract. This feeling of fatigue appears to be due to the accumulation within the muscle, during contraction, of many substances which are the products of muscular work. During rest the muscular juice is neutral, but after long-continued contraction it becomes acid. The acidification, which coincides with the development of muscular fatigue, is due to the formation of lactic acid.

In order that a muscle shall continue contractile, *i.e.*, capable of executing mechanical work, it has need of pure blood. If we

cut off the supply of blood flowing to the limb of a warm-blooded animal—say, by applying a ligature to the arteries which carry blood to it—the irritability of its muscles soon diminishes, and ultimately ceases. If, however, we remove the ligature which obstructed the flow of blood, the muscular irritability soon becomes re-established. It is obvious from this that the blood carries to the muscle substances which are essential to the continuance of its vital properties—to a continuance of its capability of performing work. The influence of the blood in reference to the muscles really appears to be twofold: carrying to them matters which are stored up within the muscular fibre, and which are decomposed during contraction (enabling the muscle to contract and do work, exactly as the coal burned in a steam boiler supplies the energy which enables the steam to do work through the intermediation of the engine); and carrying away from them those fatigue-producing substances which stop the contraction of a muscle on the application of a stimulus, even before the stock of matter capable of acting as muscle-fuel has been altogether expended.

If time did not forbid, I should desire to bring before your notice a large number of the facts with which we are acquainted relating to the properties of muscle during rest and during contraction. I would point out to you, for instance, the remarkable changes in the elasticity of a muscle which are noticed when a muscle enters into contraction; for a muscle is, curiously, a much more perfectly elastic body when it is contracted, or in action, than when it is elongated, or at rest. I would draw your attention to our knowledge as to the heat developed during muscular contraction, pointing out that whenever a muscle contracts it becomes hotter than before, and that when a muscle contracts without doing work it becomes hotter than when it contracts and does work.

As time, however, prevents my alluding to these subjects, I wish to speak to you of some very interesting phenomena of an electrical character which are presented by muscle. It can be demonstrated that all muscles when at rest are the seat of electric currents, but that when the muscles enter into contraction these currents undergo a very remarkable diminution. Some people have a vague notion that when a muscle contracts an evolution of electricity takes place. This is an entire mistake. The muscular current, as it is technically called, which exists in a muscle at rest, sinks when the muscle is thrown into contraction, the sinking being designated the "*negative variation.*"

Before demonstrating to you the existence of the muscular current I wish very much to impress upon your minds the facts which I have just stated. At a former part of this lecture I told you that we might cause a muscle to contract by exciting its nerve in a variety of ways. We might, if we chose, imitate that which normally goes on under the influence of the will by chemical, mechanical, or electrical stimulation. These facts warned you not to believe that the influence which travels along our nerves when our brains will that our muscles shall act is identical with electricity. Now, I wish you to remember that all facts are quite opposed to the view that muscular contraction is closely associated with any discharge of electricity by the muscle.

I here point to Sir William Thomson's Galvanometer, an instrument which will enable me to demonstrate to all of you the existence of a muscular current. Although the instrument appears very complicated, I shall, I trust, be able very easily to explain the principles of its construction. We have in this instrument a small magnet, to the front of which is attached a little concave mirror. This magnet is freely suspended in the centre of a coil, or rather of a great many coils, of fine copper wire. You have in this instrument 25,000 or 30,000 coils of wire surrounding the little magnet and its mirror. When an electric current passes through this coil of wire, the magnet has a tendency to place itself at right angles to it. This movement of the magnet may very easily be shown to a large number of people by a very simple contrivance. A brilliant light is allowed to fall upon the small mirror attached to the magnet, and you will observe that a bright spot of light is reflected from the mirror upon the scale to which I now point. Any movement of the magnet will cause a movement of the mirror, and the movement of the mirror will cause the spot of light to move.

You will now observe a spot of light travelling from side to side of the scale. The spot is now moving steadily, a little to the right and a little to the left of the Zero mark on the scale. If I bring anything in contact with the poles of this galvanometer which will cause a current, there will be a deflection of the spot of light.

Two wires, which are continuous with the coil of the galvanometer are brought in contact with two so-called non-polarizable electrodes; upon one of these electrodes I place the external surface of the gastrocnemius of a frog, and upon the other the transverse section of the same muscle.

I now establish a communication between the muscle and the galvanometer, and you observe the spot of light moving rapidly far away from Zero and remaining stationary near one side of the scale. This deflection indicates that a current of electricity is passing, and passing in a definite direction. I cannot explain to you here how we ascertain the direction of the passing current, but must content myself with stating dogmatically that the direction in which the spot of light has moved indicates that a current of electricity is passing from the longitudinal, or external, to the transverse surface of the muscle. Had I the time to throw this muscle into contraction, by exciting the nerve which is connected with it, you would observe that the spot of light would return *towards* Zero, indicating a diminution in the intensity of the muscular current during contraction.

I regret that the time at my disposal has compelled me to touch upon only a few of the interesting points connected with the subject of my lecture. To do that subject even very scanty justice, instead of one, many lectures would have to be devoted to it. What I have told you may, however, serve to give you an interest in the methods of investigation which physiologists are at the present time pursuing. What I have said may lead you to understand that physiology is now attaining a position exactly similar to that of the other exact sciences. We are in our investigations using instruments of precision, and, as the result of their use, we are obtaining not only exact, but, as I hope you will admit, very interesting results.

The objects of a popular scientific lecture must necessarily be rather to excite in the minds of the hearers an interest in the study and the pursuits of science than to convey a large amount of information, for it is only by patient *individual* study that we can ever attain to accurate scientific knowledge.

The Time that has Elapsed since the Era of the Cave Men of Devonshire.

A LECTURE, Delivered in the Hulme Town Hall, Manchester, on Wednesday, December 17th, 1873.

BY WM. PENGELLY, ESQ., F.R.S., &c.

I HAVE a very vivid and most agreeable recollection of the pleasure I experienced in lecturing in this room about a year ago, and, such is the principle of association, cannot help thinking that I am now lecturing to exactly the same audience.

I have been a little nervous to-day lest that young friend who was so useful to me last year might not be present on this occasion. I have not heard of his arrival, but there he is in the corner as before, and I trust that you will be so kind as to allow me to explain to him anything he may probably have forgotten in the lecture of last year, or anything that is a little technical, which, though perfectly familiar to you, may not be so well known to him.

You will remember that last year I told you that if you took this plan and laid it on the ground horizontally it would represent the ground plan of Kent's Cavern, blue being limestone, and white the part occupied with mud and stalagmite, &c., which we have excavated. My plan is not drawn on paper sufficiently large, and therefore I cannot show you all the work we have done. We have worked on for a considerable distance beyond this plan towards the south-west, and are still working in that direction. I told you that the uppermost deposit in the cavern was a series of limestone blocks, which had fallen from the roof from time to time, varying in weight from a few pounds to upwards of one hundred tons, and which were sometimes, but not invariably, cemented

together with carbonate of lime—stalagmitic matter. That which you see here represents the blocks of limestone of which I speak. Beneath and between these blocks was a black muddy accumulation varying from three inches to a foot in thickness, and which we call the *Black Mould.* It is made up almost entirely of decayed vegetable matter—in all probability leaves that had been blown into the cavern in successive autumns, for we find that plenty of leaves are blown in even now during stormy weather. In this black mould we found a great number of bones of various kinds of animals; but all of them such animals as now live, not only in the world but in various parts of Europe, and almost every one of them in Britain. Mixed with them we found a very great number of objects of an artificial character, some of the present day; for instance, a sixpence of 1846, and a halfpenny a few years older; these being the only pecuniary rewards we have received. Other articles dated back to mediæval times, such as potsherds; and others to Romano-British and even pre-Roman times. But no extinct animals, remember, were found there. Below was the *Stalagmite* formed in this way (I am aware I am speaking in a chemical presence, but I think the matter is perfectly simple, and that I shall make no great mistake): The cavern, you know, is a limestone cavern, and, so far as I know, though there are caverns in other rocks, they are far more prevalent in limestone, which are the only bone caverns with which we are acquainted. Well, rain water passing through the limestone roof, by virtue of the carbonic acid it contains—not because it is water—dissolves the carbonate of lime, *i.e.*, the limestone, and when it gets through the roof it appears on the ceiling as a drop of water, which leaves a portion of the dissolved carbonate of lime attached to the roof and forms what we call *Stalactite,* whilst the residue falls to the floor—the greater portion no doubt—and forms what we call *Stalagmite,* the distinction being one of position only, not of material. Below that, and in one part of the cavern only, near one of the entrances, was a layer from four to six inches (commonly four inches) of black matter, made up almost exclusively of charcoal or burnt wood, and termed the *Black Band.* In it were a large number of burnt bones and flint implements; and by way of enabling me to remember the exact number, the old cave men were so good as to leave behind 366 flint tools, which being the number of days in leap-year, I remember easily. Below that came a deposit known as the *Cave-earth,* the thickness of which we know nothing at all about in most cases. We have found the bottom of it in certain parts, but usually it is more th

four feet in depth, and we do not excavate to a greater depth than that below the bottom of the stalagmite. In the stalagmite we have remains of extinct as well as recent animals; and we have found flint implements. But in this (the Cave-earth) is our great harvest of extinct animals and of flint and bone implements. We have found these as far down as we have gone; and wherever the extinct animals are met with in the Cave-earth, we have also found the bone implements. I lay stress upon this because there are some people who profess to be capable of doubting whether the so-called flint tools are artificial in their origin. Metaphorically, no farther, we make them a present of the flints and say, "What do you make of bone implements such as I have in this little box that are found with them?" Man made the bone implements, there cannot be a doubt. Amongst other things we found a bone needle with a well-drilled eye in it.

Below the Cave-earth is another Stalagmite of much greater thickness, being, in some cases, little short of twelve feet thick, whilst that above the Cave-earth nowhere much exceeds five feet. The lower Stalagmite is of a totally different character to that in the higher level, and for distinction's sake we term it *Crystalline;* for it is made up of prismatic crystals totally unlike the upper Stalagmite, which, from its character, is called *Granular.*

Below the Crystalline sheet, as I told you last year, we have found a lower mechanical deposit still. But, curiously enough, whilst the upper Cave-earth is made up of very light red clay, with about fifty per cent of small angular fragments of limestone, the lower deposit, denominated *Breccia,* is a dark red sandy paste, and in it there is no limestone whatever—nothing, in fact, which that cavern hill could have furnished—but fragments of dark red grit, derived from the adjacent and loftier hills. I had better put this clearly before your eyes upon the blackboard. Omitting the blocks of limestone, we have, first, the *Black Mould*—that is the uppermost; below that we get the *Granular Stalagmite;* below that, the *Cave-earth;* below that, the *Crystalline Stalagmite;* and below that the older Cave-earth, which for distinction's sake we call *Breccia,* as I have said. Now, we may find it convenient to divide the deposits with reference to the animals found in them. I told you that in the uppermost the remains of animals such as now live occur, and amongst others, the sheep; we will therefore call that, if you please, the "Ovine" period: the sheep is never found below it. Below this, *i.e.,* in the Granular Stalagmite and Cave-earth, we found, mingled with existing species, animals no longer existing in Britain or elsewhere—animals which have not

existed in the world since the times of history, or even of tradition. Amongst them the hyæna occurred more numerously than any other animal, the horse and rhinoceros following next in frequency. We will call this the "Hyænine" period. Below this, *i.e.*, in the Crystalline Stalagmite and Breccia, we get nothing bu the remains of bear; and hence we will call this the "Ursine" period. You have there a succession of deposits arranged geologically, and also palæontologically; but let it be borne in mind that the latter is intended to apply to the Cavern only.

When addressing you last year, I told you that when we commenced our work our belief was that we should succeed in finding flint implements down as low as the Cave-earth. We knew nothing, at that time, of there being any lower deposits. Guess, if you can, how delighted we were when we found these lower deposits, and found flint implements in them as well as in those above! The Crystalline Stalagmite, almost twelve feet thick, below the Cave-earth did not show a time when man was not. Lower than that still, there was as good evidence of man as above; but it was ruder man. Here are the implements found in the Cave-earth; and there the implements, of ruder kind, found in the lower deposit—the Breccia—a totally different type of implement. That was the condition of things when I was with you last year. We have been at work, every day, ever since, and you would naturally like to inquire, "Have you found anything during the past year that comes into collision with the facts you then stated; or have you confirmed those facts?" We have confirmed them, most abundantly. There has been no conflict of evidence.

The point I reached this time twelve months was just this—that man was, in Devonshire, unquestionably the contemporary of the extinct Cave mammals; and it is very natural that two questions should prominently stand out in the minds of those who accept that conclusion from the evidence then advanced. These two prominent questions would in all probability be the following—not that they are the only questions: "How long ago was this?" and, secondly, "Where are the bones of the men who made the implements?" Now, I shall not attempt too much in this lecture. I shall not look at the second question, but deal, so far as I can, with the first, namely, "The time which has elapsed since the era of the cave-men of Devon;" and I am afraid I shall disappoint some of you at once if I adopt the philosophical habit of saying, when it is necessary and right and proper to say it, I cannot tell you how long ago it was. If you wish me to express it in years or

even in centuries, I know nothing at all on the question; but this I know, that it was much longer ago than our fathers believed, even in their most sanguine dreams. With reference to attempting to express the time in years or in astronomical units—for you know a year or a day is merely an astronomical unit—instead of attempting to do that, allow me to quote to you a brief passage from the admirable paper read by Mr. Prestwich to the Royal Society, June 19, 1862. Speaking on this point he says—and the figure has always appeared to me to be very striking, grand, and bold:—

Just as, though ignorant of the precise height and size of a mountain range seen in the distance, we need not wait for trigonometrical measurement to feel satisfied in our minds of the magnitude of the distant peaks, so with this geological epoch, we see and know enough of it to feel how distant it is from our time, and yet we are not in a position at present to solve with accuracy the curious and interesting problem of its precise age.

That is just the position in which the question now stands; though I must tell you that, since Mr. Prestwich wrote these words, the discovery of the lower deposits, just described, has been made, and of these still ruder men.

There are five lines of inquiry, or five lines of evidence, which one has to consider in a question like this.

First, we may deal with the deposits in the cavern, or what may be called the *Geological* evidence. Secondly, with the animals found in the deposits, or what may be called the *Palæontological* evidence. Thirdly, we may deal with the implements as we have them before us, which may be called the *Archæological* evidence. Fourthly, we may deal with the changes that have taken place in Britain in its relation to the Continent, and the changes that have taken place in the configuration of the external surface of the immediate district, which we may call the *Geographical* evidence. And, lastly, we may deal with the thermal indications, the indications which the animals found present of the climate of that time, or the *Climatological* evidence. These are the five lines of evidence which, if time permitted, I should like to dwell on this evening. I feel perfectly satisfied, however, that the material is enough for three lectures, and I have tried my hand too many times at the attempt to give three lectures in one to warn me against attempting to do anything of the kind at present. So far as time will allow us we will go.

First, then, the *Geological* evidence. I fancy I hear my young friend say, "Is it not possible that in your deposits you may have some potted anachronisms—things belonging to different periods commingled? and may it not be that the things which you

think belong to one period belong really to very different periods?" I reply, That is possible in some cases; we will see whether it applies here. To show you how possible that is, let me tell you the following fact which occurred in my own experience. There is in central Devon, near the little town of Hatherleigh, an alluvial plain that has been formed by the little river Lew, which wanders through it. On that plain there are large trees growing—notably many oaks—and some of them are at least three feet in diameter. There is good evidence that in its wanderings the river has occupied every part of that plain at one time or another. But it is clear that if I find an oak tree standing three feet in diameter the river has never invaded that spot since the acorn germinated which has been developed into that oak. It happened, however, that the river having encroached on the situation occupied by one of the oaks shortly before I visited the locality, the tree was somewhat undermined. Then came an envious wind which blew in the direction so as to prostrate the tree, which fell obliquely across the river. The result was that the obstructed river cut out another channel for itself, and in doing so exposed an old oak tree which had been prostrated in the same way long, long ages ago. The swollen river took no notice of this obstacle, but when it fell to its usual dimensions it flowed on one side of the old tree, and began to silt it up. But the river brought down and lodged by the side of that old tree a tin kettle and a port wine bottle. I saw them being silted up, and said to my geological friend—"Look here; some future geologist will take this out, you know, and say, 'This is a very strange thing that men who were so highly civilised as to drink port wine should neglect so valuable a thing as a great oak tree.' We, however, know a little better; the things do not belong to the same period." Are there any such potted anachronisms in our cavern deposits? I have already told you that in the Black Mould, or uppermost deposit, not more than three to twelve inches in thickness, we found lying together a sixpence of 1846 and pre-Roman objects. If we ascribed them to the same age we should make a similar blunder to the one I have supposed in the case just described. We admit it is possible in either of the mechanical deposits for things of different ages to be commingled, but we contend that that is utterly impossible in the Stalagmites. Remember how the Stalagmite is formed. There lies on the floor of the cavern an object, and the drip from the roof falls upon it. As you stand in the cavern and listen you can hear the dripping of the water, and you know that a work is in progress which only requires sufficient time to make the deposit

reach any thickness you like to mention. You know perfectly well that that drip will cover the object and seal it down there firmly, and if hereafter another object happens to be deposited above it will be sealed down in like manner; and if you break that floor up the position of those objects in that deposit will be their original position, the lower will be the older. Objects in the Cave-earth, however, may be of different ages; but this I assert, that the most modern object in the Cave-earth is necessarily and certainly more ancient than the most ancient object in the Stalagmite above it. So I say again, that the most modern object in that Stalagmite is more ancient than the most ancient lying in the mechanical deposit—the Black Mould—above. Though, then, there may be anachronisms, if you confine yourself to any one of the mechanical deposits, there can be nothing of the kind if you take the succession of deposits. I think that point is clear.

Well, I have told you that we found Romano-British and pre-Roman objects in the Black Mould, but nothing of the kind below; and that we found no extinct animals in the uppermost deposit. We feel perfectly satisfied then that this deposit is worth, as a minimum, 2,000 years; it may be worth a great deal more, but we can afford to be generous in this matter, and we will say 2,000 years as our starting-point. We have not gone back to the time of extinct animals, remember. The moment we pass below that Black Mould and get into the *Granular Stalagmite*, no matter how shallow is our first scratch, we feel that we have gone back to more ancient times—no more pottery, nothing of the pre-Roman, or the Romano-British, or mediæval character: more than that, we find ourselves at once in the presence of the extinct animals. I have myself taken out of that Stalagmite teeth of the mammoth, teeth of the extinct cave bear, teeth of the extinct rhinoceros, teeth of the hyæna, which, only partially buried in the Stalagmite, were jutting up an inch in relief in some instances. So that I feel perfectly satisfied that there is an interval of time utterly unrepresented between the two deposits. Now comes the question—How much time does that *Granular Stalagmite* represent? Remember you cannot, on the whole, build a wall faster than the clay is dug for making the bricks; neither can a stalagmitic floor be formed faster than the limestone overhead is dissolved; and the rate at which that is dissolved depends on the amount of carbonic acid in the water.

Under existing circumstances we feel perfectly satisfied that it must be very slow work; and when we bear in mind that a portion of the dissolved limestone is retained on the roof to form

stalactites, that only a portion is utilised in forming the floor, we feel fully convinced that the rate at which the floor is formed is necessarily slower than the rate at which the limestone is dissolved. Now, when we take stalagmite which is tolerably firm, and polish it, we find that it is made up of the thinnest possible laminæ, thinner even than ordinary writing paper, justifying the conclusions to which chemistry led us. The laminæ indicate intermittences in the slow supply of material from above. I feel that it is necessary to be on one's guard in speaking on this subject, inasmuch as a highly esteemed friend of mine has recently given a good deal of attention to the rate at which stalagmite is formed in a cavern in Yorkshire. The work he has done in that direction is of the highest possible value—in fact, to use an American expression, is a "caution." I doubt, however, whether it is at all wise to apply the rate at which stalagmite is formed in one cavern as a measure of the time represented by the stalagmite existing in another cavern. I know perfectly well that the rate at which stalagmite is formed in some branches of Kent's Cavern is utterly unlike that at which it is formed in other branches of the same cavern. With that caution before my eyes, I proceed. We know that in Kent's Cavern there are inscriptions on the granular stalagmite; and we know further that the lines of drainage of the cavern have not changed. Wherever the stalagmite is found very thick, the drip is now unusually copious in rainy weather; wherever the stalagmite is of moderate thickness, the drip is not very considerable; and wherever there is any part of the cavern perfectly dry, without any drip at all, there there is no stalagmite at all. It would seem that the lines of drainage in the cavern have always been the same. Further: suppose this to be the limestone roof of the cavern, and here a small hole for the discharge of the carbonate of lime. There is a pendant there in the form of a stalactite, and towards that there always, without any exception, rises from the floor below a boss to meet it. It seems therefore that the water has entered the cavern at precisely the same points at all times. Now, let us return. On a boss of stalagmite there is the following inscription: "Robert Hedges, of Ireland, Feb. 20, 1688." That is 185 years ago. There is another inscription, which had not been noticed until last June, which is earlier still, dated 1604, that is 269 years old. Let us say 250; we can afford to be liberal. Now we know perfectly well that those inscriptions are genuine; and this is the evidence. The Rev. Mr. MacEnery, who was the first to render Kent's Cavern famous, describes the inscription I first mentioned, that of 1688, and another of 1615.

His MS. description is in my possession as Hon. Secretary of the Torquay Natural History Society. That description was written in 1825, therefore we know the inscriptions are good for 48 years. Further, he tells us that the inscriptions are slightly glazed over by a film of stalagmite accreted on them since they were cut. That description applies to them now so accurately that the forty-eight years which have elapsed since have made no appreciable change, and yet the calcareous water has been going on constantly dripping. There is no shadow of doubt that those inscriptions are genuine. Now, how much carbonate of lime has accreted on those ancient inscriptions made 250 years ago? Not more than the twentieth of an inch. I mention this a little emphatically, because my friend Mr. Wallace, in an article which appeared in *Nature* a few weeks ago, when writing on these very cavern inscriptions, misunderstands my words, and puts it down at the rate of an eighth of an inch, instead of a twentieth of an inch. Now, if it has taken 250 years to form the twentieth of an inch in thickness in a part of the cavern where the stalagmite has been formed with unusual rapidity, judging from these bosses, you perceive clearly enough that it would take twenty times that amount of time at that rate to represent an inch, that is, 5,000 years, and we have fully five feet to account for in the Granular Stalagmite only. Now, ladies and gentlemen, are you prepared for that amount of time? Five thousand years for an inch, and sixty inches—sixty times 5,000 years! What then? After you have got below the Cave-Earth you have another stalagmite little short of twelve feet in thickness, and you have that to account for in addition! Now let me give you a caution. I am not prepared to insist on your receiving that rate as a chronometer. I am willing to admit that it may have been faster, for anything I know to the contrary; but supposing it were fifty times as fast—and that I take to be a very high estimate indeed—were our fathers prepared for the reception of the time thus obtained? Bear in mind, moreover, that what we are talking about is the time that has elapsed since the era of the Cave Men of Devon, and unless you believe that Devonshire was the cradle of the human race, that the first man had the good taste to appear in the world in Devonshire, you perceive that the question of *the antiquity of man in Devonshire* will fall very far short indeed of the *antiquity of man* in the world. Well, passing that by, I would ask those who object to receive the chronometer furnished by the stalagmitic facts of Kent's Cavern, extending over at least 250 years, to tell us why they object to it. They say the stalagmite may have been formed

more rapidly. Well, if that be so, there must have been some reason for it. Was there more carbonic acid in the atmosphere? Geology gives no hint that such has been the case. Was there a more luxuriant Flora which, by the decomposition of the plants, furnished more carbonic acid to the water? If that be so, the climate must have been warmer. But our facts assure us the climate was not warmer, but colder. Was there more rain? Even waiving the fact that rain water without carbonic acid would not effect a greater solution of carbonate of lime—more rain implies more evaporation, and more evaporation a higher temperature. The hill is at present isolated, and some of my friends have said that formerly, perhaps, the whole drainage of the country was precipitated on the cavern hill from the greater heights. I say it may have been so; but do you not perceive that this implies a great change in the configuration of the surface? And that would carry you further into time than even taking the rate at which the stalagmite is at present formed.

I pass now from this question of the stalagmite, believing, however, that I might leave the question solely on that basis, and you would be convinced that our fathers did not assign a sufficiently high antiquity to the human race in Devonshire.

I come now to the Cave-earth. Whence that Cave-earth? You know that limestone is not perfectly pure. I am afraid that limestone is not peculiar in that respect, and that there are not many things that are perfectly pure. There is in some limestones a considerable amount of earthy matter, and when the carbonate of lime is dissolved out by the carbonic acid in the water, there is an earthy residuum which may have supplied some of the material of the Cave-earth. But there are facts connected with the cavern which show that it must have been extremely minute in quantity. That the Cave-earth came from without and was washed in at the entrances, is clear to those who will go there and examine the cavern; and it is also indicated by the fact that in the prodigiously thick stalagmites no portion of earthy residuum is mixed up with them. One would have supposed that if any considerable amount of Cave-earth was derived from the limestone above, some proofs of it would be seen in the stalagmites. I have no doubt that the Cave-earth came in through the two entrances, and in extremely minute instalments. Wherever we find in the Cave-earth a narrow stone or a bone, in almost every instance that stone or that bone is found to be invested with a thin film of stalagmite, the interpretation of which cannot be far to seek. There where it lay was the upper portion, or floor of the cavern for a very long time. During that

time the drip from the roof brought stalagmitic matter down which formed a film around the object. The process was interrupted by the introduction of a thin layer of Cave-earth, and just above it we find another bone or stone under precisely the same conditions; and that goes on throughout the entire thickness of the Cave-earth. When we move one of the large blocks of limestone found in the Cave-earth, and find a bone under it, we find that bone crushed, the parts lying in juxtaposition. Again, the bone was broken by that stone falling on it. The bone lay on a firm, unyielding surface, and when the stone came down the former was broken, thanks to the unyielding character of the deposit below. Everything concurs to show that the Cave-earth was introduced very, very slowly. You perceive, therefore, that the Cave-earth must represent a very large amount of time. We go then further back to the older or Crystalline Stalagmite, and further back still to the Breccia. I cannot now afford to give another moment to this part of my question, excepting, perhaps, to say that the Breccia, this lower deposit, is formed of materials utterly unlike the Cave-earth, showing that the configuration of the surface had entirely changed, and that the materials introduced into the cave in the era of the earliest deposit were not introducible, if I may use such an expression, in the subsequent eras. The material is utterly unlike: you have a different Fauna, a different kind of material, different configuration of the surface, and yet you have the men there. That is the evidence, hastily gone over, derived from the *geological* aspect of the question.

I come now to the Palæontological evidence, namely, the kind of animals found. There was published in our Report, in 1869, by my friends, Mr. Boyd Dawkins and Mr. Sanford, the list of the animals found in the Cave-earth. It is as follows:—The Cave Lion, *Felis* of the size of the Lynx, Wild Cat, Cave Hyæna, Wolf, Fox, *Canis vulpes* var. *spelæus*, *Canis* of the size of Isatis, Glutton, Badger, Cave Bear, Grizzly Bear, Brown Bear, Mammoth, *Rhinoceros tichorhinus*, Horse, Urus or Wild Bull, Bison, "Irish Elk," Red-deer, Reindeer, Hare, *Lagomys spelæus*, Water Vole, Field Vole, Bank Vole, *Arvicola gulielmi*, and Beaver. To these I was enabled to add, in 1873, *Machairodus latidens*. The last-named, the famous *Machairodus latidens*, has not been found anywhere else in Britain, though it has been found on the Continent. In this list you have three groups of animals: animals utterly extinct from the world; animals not extinct, but exterminated from Britain, such as the reindeer; and animals that still exist in Britain, such as the fox and the hare. You will perceive then clearly enough that, what-

ever caused the extinction of the animals, was a cause that operated on some and not on all. It was a potent cause, so far as those affected by it were concerned; it was not a very potent cause, inasmuch as a great number of animals were enabled to live through the changes, whatever they may have been. It is perfectly clear that it was nothing in the nature of a great convulsion such as the earlier geologists used to talk about, a convulsion which synchronously and universally depopulated the globe. Since life first appeared on the globe there is no reason to believe that the globe has been without life at any time. It was not due to convulsion, then; nor was it exclusively due to man. Even such a cosmopolitan animal as the mammoth, which has been found nearly all over the northern hemisphere, has disappeared, unless we believe an American story just now circulating. I am sorry to say that it is American; I hope I offend nobody. The mammoth disappeared even before the times of tradition. I am perfectly aware that such an animal as the mammoth would be a good mark for the clumsiest sportsman; and it is certain that such animals in such a country as ours would have been got rid of. But we have to do with animals that are small as well as large. For instance, take the lagomys, the tailless hare, the pika, as we call it—that animal is smaller than a good-sized rat; and when any one asks me to believe that these animals were rendered extinct through man's agency, I say, "My friend, have you any rats in your premises? When you can rid your premises of rats, I will believe that man might have driven the lagomys from the world, but not till then." Man had comparatively very little to do with the extinction of these animals, you may rely upon it. If then it was not by convulsion; if it was not by any action that was potent, so far as the entire animal kingdom was concerned, if it were potent only for certain forms, where is the probability that those animals became extinct all at once, or synchronously? I rather look at it as a case like Exeter Cathedral, the west front of which is very beautiful, having in it a great number of niches occupied with figures of saints and kings. We can suppose that some great earthquake might shake a large number of those figures out of their niches. But what is the fact? Some of the niches are vacant; some of the figures are moving to destruction, but it is a slow and gentle process; you can hardly say how it goes on. So the extinction of animals from the face of this earth was a slow and gentle process—one dropped out of existence—the world had become unfit for it; or it had been differentiated into a slightly different form so as not to be recognisable; and after a very considerable lapse of time

another disappeared; so that to the mind of any palæontologist the extinction of so many animals that were living at the time when these cavern deposits were introduced, is a proof of the prodigious lapse of time.

I pass now—for I see my time is passing too—to the *Archæological* evidence, that is, the evidence of the implements we have found. Archæologists have found it convenient and possible to divide all human time prior to the present day, in Western Europe, into certain ages. I need not tell the men of the North that we are living in the *Iron age.* I dare say I need not tell any of you that there was a time—if you dig into the deposits which occupy the surface of the earth, and if you go further and further back—when iron appears not to have been used. I do not say whether that applies to all the world; what I do say is that in Western Europe such is the fact. I may say, in passing, that there has been a little puzzle in the minds of antiquaries respecting the use of iron. Iron, you know, does not occur native in this world, except when it comes in the shape of meteoric stones; and it has been a puzzle to understand how men first hit upon the idea of getting iron out of the iron ore. Now, the earliest mention of iron is in an Egyptian document, if I may call it so, and it curiously turns out that the earliest name given to iron was "stone from heaven." I have that on the authority of the best Egyptologists in the nation, and it appears that the first iron used in Egypt was native or meteoric iron. Well, prior to the iron age the deposits below those containing iron, contained bronze, and hence the archæologists speak of the age prior to that of iron under the name of the *Bronze age.*

I jump over the fact that there seems to have been a short period during which copper, without any admixture of tin, was used. We come now to the time when metal was not used at all, and stone implements were alone employed; but the people had the skill to polish their implements to increase their efficiency; and that would be called the polished stone age, or, to use Sir John Lubbock's happy expression, the *Neolithic age*—the new stone age. Earlier still, according to the age of the deposits, was the time when we find stone implements which are never polished. They are the oldest, and belong to what we call the *Palæolithic*, that is the ancient stone, *age.* Now, all the implements found in Kent's Cavern are of this *palæolithic* kind.

You will bear in mind, if you please, that another point of very considerable interest in the cavern is this, that the implements in the Cave-earth belong to what I have called the hyenine period,

whilst those in the Breccia belong to the ursine or. bear period (I am speaking now of Kent's Cavern only). The former are delicately-made implements, but never polished, all made out of flakes; whilst the latter are massive implements and are invariably made out of flint nodules, and not flakes. The difference is as if the old men took a tree and scraped it hollow, and made a canoe of it; the more civilised and more intelligent and skilful men cut the tree into planks and fastened the planks together and made a ship. There they took the nodule, and the nodule was the implement, and there are traces of its formation on the surface; here they took the nodule, but struck off a plank or flake of flint, and fashioned it into a more delicate implement. Though they are all palæolithic, they belong to two different types. It has been suggested that we should call the more delicate ones (it is a violence to language) *palæolithic*, and the others *archaic*. It may be a convenient distinction; at any rate the tools of the ursine period are older, and we know that they are a great deal ruder, and more massive also. Passing, however, from that, I ask you to accompany me to Denmark, and there the naturalists have been able to get a chronology out of the peat bogs. You are aware that Denmark is a land of beech trees. There are bogs in Denmark, and on their surface are found the *debris* or refuse of beeches. Below the beech there comes a time when there was no beech, but oaks of a particular kind, having leaves with a long foot-stalk, and therefore called the *pedunculated oak*. Below that there is another form of the oak tree, the leaves having scarcely any foot-stalk, and hence named the *sessile oak*. Below that again we have other trees, but the Scotch fir is by far the most prevalent. There you have the chronological series. Now let us endeavour to attach a time value to them. In the first place we are quite sure that the beech period represents more than 1,800 years, for the Romans inform us that Denmark was a land of beech trees 1,800 years ago. They found the beech in possession of Denmark; it had taken possession then before their arrival; and we cannot err if we go back some 200 hundred years before that, and say 2,000 years ago the beech era commenced; it may have been more—it cannot be less. The beech trees show no indication of giving up their hold of Denmark at present. As the density of the population increases the beech will disappear, thanks to man. I think we shall be safe if we allow that, if man had not interfered, the beech would have lasted 500 years more; that would give 2,500 years for one species of tree in Denmark, and prior to that that tree was not there. Prior

to that we had the oaks, and prior to that again we had the fir. The Scotch fir not only does not grow in Denmark now, but will not grow even when coaxed and petted by the horticulturist; the country has become unsuited to it. Now, if we take these periods and multiply them by 2,500, you will get something like 10,000 years as representing the actual large amount of time; but whether so large or larger is not perfectly certain. Let us try if we can co-ordinate these facts, and see how they will jump with the archæological evidence. The iron tools seem to come down about as far as the beech, and no further. The bronze tools go below the first oak and perhaps half-way into the sessile variety. Below that, down to the bottom of the fir, we have the neolithic or polished flint tools. Thus, you perceive, that though thousands of years are absorbed in that way, and we go back to the lower levels, we have not got back to the Kent's Cavern upper or Granular Stalagmite yet.

Now let us co-ordinate that with the animals. Animal remains are found in considerable abundance in the bogs, but all the way down they are recent; there is no single extinct animal. Again, we have not got back to the upper Stalagmite. Now let us come to the cavern. The Black Band would be coeval with the bottom of the bogs; then we have below it the Granular Stalagmite; below that again the Cave-earth; below that again the Crystallised Stalagmite; and below that again the Breccia. The hyænine period goes back to the Cave-earth, and the ursine period is below or older still. That is a series of stepping-stones by which I have endeavoured to conduct you through the enormous amount of time passed since the era of the cave men of Devonshire. Let us recapitulate—2,500 years is the minimum for the Beech era of Denmark, or an average probably also for each of the earlier bog eras. The whole of these do not take us back beyond the Neolithic implements; they take us back to them through the iron and bronze ages, but fail to reach the Palæolithic tools. When we have got here we are but in the Black Mould of the cavern. Below that we come to that great deposit of Granular Stalagmite, formed, so far as we can make out, at the rate of the 20th of an inch in 250 years, and there are five feet to account for. All that amount of time absorbed, we are back into the Cave-earth period, representing a prodigious amount of time, during which vast herds of animals lived in this country. We go back further still when there was no hyæna, and nothing indicating his presence—none of the bones gnawed after his particular fashion. And when we remember that the hyæna was a cave-haunting animal, the fact that

it was not found in that cavern is tolerable proof that the hyæna was not in this country; and that therefore after this time when the hyæna was not, it was possible for the hyæna to come here. In other words, after the men of the Breccia or Ursine period Britain was connected with the Continent, the English Channel was dry, and the hyæna and perhaps all his companions came to this country. Far back as those successive times take us, and they do so almost to bewilderment, they do not take us back to the beginning of man even in this country.

I will ask you to bear one or two other facts in mind. First of all, I have brought before you three witnesses, and have given them the grand names of geology, palæontology, and archæology. They fail to state how long ago the time was to which they point; none of them are perfectly mathematical in their demonstrations, but they concur in such a remarkable way as to afford an amount of evidence stronger perhaps than any one of them alone if it had been even mathematically definite and exact. When you bear in mind, again, that the rate at which savage tribes emerge from savagedom when left to themselves is so excessively slow that Archbishop Whateley and others held that the savage would never emerge from that state, which may be taken as an hyberbolical mode of saying that his emergence would be extremely slow—when you bear in mind that slowness, and pass back through the *Iron* age, the *Bronze* age, the age of polished stone implements, the age of unpolished but somewhat symmetrical stone tools, back to the time when there were nothing but those massive implements still more rudely wrought—I say when you take all that into consideration, and bear in mind how slowly man emerges, and especially how slowly when the state from which he has to emerge is low, I think that fact of itself is sufficient to justify the conclusion that the time of the men which we have been contemplating was very far more distant from us than that which our forefathers imagined. Perhaps some one may say, "O, but these men never emerged; the palæolithic men did not become civilised into neolithic men; the neolithic men came in and conquered them. It is true their advance in civilisation would represent a large amount of time, but there was no such advance." If that view be correct, this early period presents you with different races of human beings, and the common ancestor from whom those different races sprang must be placed further back still. Take any view you like of it, whether the view that the archaic men were self-developed into palæolithic men, and those into neolithic men, and those into metal tool-making men—take what view you

like, either that or the view that these different states of civilisation represent different races, you cannot get rid of the idea of a vast amount of time.

Now one word more, and I have done. I do not say that the first men that appeared on this earth were savages, potential or actual. I know nothing about that point; but this I do say, that these men of antiquity have been savage in proportion as they are ancient. If the men who first appeared on this earth were pretty much like ourselves in their powers and gifts, and the ancient cave men were comparatively modern descendants of intellectual ancestors, you are again pledged to a long antiquity.

I apologise for having kept you so long, and thank you for the kind reception you have given me. You observe that I have left untouched two lines of evidence, having said nothing about the *geographical* or the *climatological* argument. Time will not admit of that. Each of these subjects is long enough for a lecture.

Crystalline and Molecular Forces.

A LECTURE, Delivered in the Free Trade Hall, Manchester, on Wednesday, October 28th, 1874.

BY PROFESSOR TYNDALL, F.R.S.

A FEW years ago I paid a visit to a large school in the country, and was asked by the principal to give a lesson to one of his classes. I agreed to do so provided he would let me have the youngest boys in his school. To this he willingly assented; and, after casting about in my mind as to what could be said to the little fellows, I went to a village hard by and bought a quantity of sugar-candy. This was my only teaching apparatus. When the time for assembling the class had arrived I began by describing the way in which sugar-candy and other artificial crystals were formed, and tried to place vividly before their young minds the architecural process by which the crystals were built up. They listened to me with the most eager interest. I examined the crystal before them, and when they found that in a certain direction it could be split into thin laminæ with shining surfaces of cleavage, their joy was at its height. They had no notion that the thing they had been crunching and sucking all their lives embraced so many hidden points of beauty. At the end of the lesson I emptied my pockets among the class, and permitted them to experiment upon the sugar-candy in the usual way.

When asked to come here and lend a helping hand in what I believe to be a truly good work (though hard pressed by other duties), I could not refuse the invitation.

I know not whether this great assembly will deem it an impertinence on my part if I seek to instruct them for an hour or so on the subject chosen for my little boys. In doing so I run the imminent risk of being wearisome as well as impertinent, while labouring under the further disadvantage of not being able to make matters pleasant at the conclusion of the lecture by the process adopted at the end of my lesson to the boys.

We are to consider this evening the phenomena of crystal-

lisation; but in order to trace back the genesis of the notions now entertained upon the subject, we have to go a long way back.

In the drawing of a bow, the darting of a javelin, the throwing of a stone, in the lifting of burdens, and in personal combats, even savage man became acquainted with the operation of *force*. His first efforts were directed towards securing food and shelter; but ages of discipline—during which his force was directed against nature, against his prey, and against his fellow-man—taught him foresight. He laid by at the proper season stores of food, and thus obtained time to look about him, and become an observer and inquirer. He discovered two things, which now more specially interest us, and sent down to us the knowledge of his discovery. He found that a certain resin dropped from the amber-tree possessed, when rubbed, the power of drawing light bodies to itself, and of causing them to cling to it; and he also found that a particular kind of stone exerted a similar power over a particular kind of metal. I allude, of course, to the loadstone, or natural magnet, and its power to attract particles of iron. Previous experience had enabled our early inquirer to distinguish between a push and a pull. In fact, muscular efforts might be divided into pushes and pulls. Augmented experience showed him that in the case of the magnet, pulls and pushes—attractions and repulsions—were also exerted; and, by a kind of poetic transfer, he applied to things external to himself the conceptions derived from the exercise of his own muscular power. The pushes and pulls of the magnet and of the rubbed amber were to him also force.

In the time of the great Lord Bacon the margin of these pushes and pulls was vastly extended by Dr. Gilbert, a man probably of firmer fibre, and of finer insight, than Bacon himself; who, moreover, was one of the earliest to enter upon that career of severe experimental research which has rendered our science almost as stable as the system of nature which it professes to explain. Gilbert proved that a multitude of other bodies, when rubbed, exerted the power which thousands of years previously had been observed in amber. In this way the notion of attraction and repulsion in external nature was rendered familiar. It was a matter of experience that bodies between which no visible link or connection existed, possessed the power of acting upon each other; and the action came to be technically called "action at a distance."

But out of experience in science there always grows something finer than mere experience. Experience, in fact, only furnishes the soil for plants of higher growth; and this observation of action at a distance furnished material for speculation upon the

largest of all problems. Bodies were observed to fall to the earth. Why should they do so? The earth was proved to roll round the sun; and the moon to roll round the earth. Why should they do so? What prevents them from flying straight off into space? Supposing it to be ascertained that from a part of the earth's rocky crust a firmly-fixed and tightly-stretched chain started towards the sun, we might be inclined to conclude that the earth is held in its orbit by the chain—that the sun twirls the earth around him as a boy twirls a bullet at the end of a string round his head. But why should the chain be needed? asks the speculative mind. It is a fact of experience that bodies can attract each other at a distance, and without the intervention of any chain. Why should not the sun and earth so attract each other? and why should not the fall of bodies from a height be the result of their attraction by the earth? Here then we have one of those higher thoughts of speculation which grow out of the fruitful soil of observation. Having started with the savage and his sensations of muscular force, we pass on to the observation of force exerted between a magnet and rubbed amber, and the bodies which they attract, and rise by an unbroken growth of ideas to a conception of the force by which sun and planets are held together.

This idea of attraction between sun and planets had become a familiar one in the time of Newton. He set himself to examine the attraction, and here, as elsewhere, we find the speculative mind falling back for its materials upon experience. It had been observed, in the case of magnetic and electric bodies, that the nearer they were brought together the stronger was the force exerted between them; while, by increasing the distance, the force diminished until it became insensible. Hence the inference that the assumed pull between the earth and the sun would be influenced by their distance asunder. Guesses had been made as to the exact manner in which the force varied with the distance; but, in the case of Newton, the guess was supplemented by being brought to the severe test of experiment and calculation. Comparing the pull of the earth upon a body close to its surface, with its pull upon the moon, 240,000 miles away, Newton rigidly established the law of variation with the distance, thus placing in our hands a principle which enables us to determine the date of astronomical events in the far historic past or in the distant future.

But on his way to this great result Newton found room in his ample mind for other conceptions, some of which, indeed, constituted the necessary stepping-stones to his result. The one which here

concerns us most is this: Newton proved that not only did the sun attract the earth, and the earth attract the sun, *as a whole*, but that every particle of the sun attracts every particle of the earth, and the reverse. His conclusion was, that the attraction of the masses was simply the sum of the attractions of their constituent particles.

This result seems so obvious that you will perhaps wonder at my dwelling upon it; but it really marks a turning point in our notions of force. You have probably heard of late of certain disturbers of the public peace named Democritus, Epicurus, and Lucretius. These men adopted, developed, and diffused the dangerous doctrine of atoms and molecules which found its consummation in this city of Manchester at the hands of the immortal John Dalton. Now, the grand old pagans whom I have named, and their followers up to the time of Newton, had pictured their atoms as falling and flying through space, hitting each other, and clinging together by imaginary claws and hooks. They entirely missed the central idea that the atoms and molecules could come together, not by being fortuitously knocked against each other, but by their own mutual attractions. This is one of the great steps taken by Newton. He familiarised the world with the conception of *molecular force*.

But the matter does not end here; experience had given us the key to further mysteries. In the case of electricity and magnetism a double exercise of force had been observed—repulsion had been always seen to accompany attraction. Electricity and magnetism were examples of what are called *polar forces;* and in the case of magnetism, experience itself pushed the mind irresistibly beyond the bounds of experience, compelling it to conclude that the polarity of the magnet was resident in its molecules. I hold a strip of steel by its centre, between my finger and thumb. One half of the strip attracts, and the other half repels the north end of a magnetic needle. I break the strip in the middle, and what occurs? The middle point or equator of the magnetism has shifted to the centre of the new strip. This half, which a moment ago attracted throughout its entire length the north pole of a magnetic needle, is now divided into two new halves, one of which wholly attracts, and the other of which wholly repels, the north pole of the needle. Thus the half when broken off proves to be as perfect a magnet as the whole. You may break this half, and go on breaking till further breaking becomes impossible through the very smallness of the fragments; still you find at the end that the smallest fragment is endowed with two poles, and is, therefore,

a perfect magnet. But you cannot stop here: you *imagine* where you cannot *experiment*; and reach the conclusion entertained by all scientific men, that the magnet which you can see and feel is an assemblage of molecular magnets which you cannot see and feel, but which must be intellectually discerned.

I shall endeavour to show you some of the actions of this polar force, at the same time asking you to remember that my main object here to-night is to show you the growth of scientific ideas, and to illustrate the manner in which the scientific investigator uses his thoughts and his hands in the investigation of nature.

Scientific ideas, as already stated, spring out of experience, but they extend beyond the boundary of experience. And, indeed, in this power of ideal extension consists for the most part the differences between scientific men. The man who cannot break the bounds of experience, but holds on to the region of sensible facts, may be an excellent observer, but he is no philosopher, and can never reach those principles which bind the facts of science together. True, the speculative faculty may be abused like all good things, but it is not men of science that are most likely to abuse it. When he accounted for the heat of chemical combination by referring it to the clash of atoms *falling* together, a townsman of your own described an image presented to his mind but entirely beyond the reach of his senses. It was, however, an image out of which grew memorable consequences; among others this one of a personal nature. The walls of this Free Trade Hall, or rather its predecessor, have rung with the speeches of Cobden, and Bright, and Wilson. But at the time when their words rolled round the world a scientific worker was silently and studiously engaged in your city grappling with the problem, how out of heat is extracted mechanical force, and by implication with far higher problems. He grappled with it successfully, bringing it into the full light of experimental demonstration. And I venture to affirm that in the coming time, not even the great orators and politicians just named, not even the greatest of your manufacturing princes, will enjoy a purer, a more permanent or enviable fame—there is not a man amongst them of whom Manchester will be more justly proud than of her modest brewer, but renowned scientific worker, James Prescott Joule.

You will pardon this momentary deflection from my subject. We have now to track still further the growth of our notions of force. We have learned that magnetism is a polar force; and experience also hints that a force of this kind may exert a certain structural power. It is known, for example, that iron filings strewn round

a magnet arrange themselves in definite lines, called, by some, "magnetic curves," and, by Faraday, "lines of magnetic force." In these observed results of magnetic polarity we find the material for speculation, in an apparently distant field. You can readily make an experiment or two for yourselves with any magnet. My excellent assistant, Mr. Cottrell, places two magnets before me, and over them a sheet of paper. Scattering iron filings over the paper and tapping it, the filings arrange themselves in a singular manner. There is a polar force here in action, and every particle of iron on the paper responds to that polar force, and the consequence is a certain structural arrangement—if I may use the term—of the iron filings. Here is a fact of experience which, as you will see immediately, furnishes further material for the mind to operate upon, rendering it possible to attain intellectual repose and satisfaction while speculating upon apparently remote phenomena.

You cannot enter a quarry and scrutinise the texture of the rocks without seeing that it is not perfectly homogeneous. If the quarry be of granite, you find the rocks to be an agglomeration of crystals, of quartz, mica, and felspar. If the rocks be sedimentary, you find them, for the most part, composed of crystalline particles derived from older rocks. If the quarry be marble, you find the fracture of the rocks to be what is called crystalline fracture. These crystals are, in fact, everywhere. If you break a sugar-loaf, you find the surface of fracture to be composed of small, shining, crystalline surfaces. In the fracture of cast iron you notice the same thing; and next to his great object of squeezing out the entangled gas from his molten metal, another object of your celebrated townsman, Sir Joseph Whitworth, when he subsequently kneads his masses of white-hot iron as if they were so much dough, is to abolish this crystalline structure. The shining surfaces observed in the case of crystalline fracture are surfaces of weak cohesion; and when you come to examine large and well-developed crystals, you soon learn why they are so. I try the crystal of sugar referred to at the beginning of this lecture in various directions with the edge of my knife and find it obdurate; but I at length come upon a direction in which it splits clearly before the knife, revealing two shining surfaces of cleavage. Such surfaces are seen when you break cast iron, and the metal is strengthened by their abolition. Other crystals split far more easily than the sugar.

In the course of scientific investigation, then, as I have tried to impress upon you, we make continual incursions from a physical

world where we observe facts, into a super or sub-physical world, where the facts elude all observation, and we are thrown back upon the picturing power of the mind. By the agreement or disagreement of our picture with subsequent observation it must stand or fall. If it represent a reality, it abides with us; if not, it fades like an unfixed photograph in the presence of subsequent light. Let me illustrate this. You know how very easy it is to cleave slate rock. You know that Snowdon, Honister Crag, and other hills of Wales and Cumberland, may be thus cloven from crown to base. How was the cleavage produced? By simple bedding or stratification, you may answer. But the answer would not be correct; for, as Henslow and Sedgwick showed, the cleavage often cuts the bedding at a high angle. Well, here, as in other cases, the mind endeavouring to find a cause passed from the world of fact to the world of imagination, and it was assumed that slaty cleavage, like crystalline cleavage, was produced by polar forces. And, indeed, an interesting experiment of Mr. Justice Grove could be called upon to support this view. I have here, in a cylinder with glass ends, a fine magnetic mud, consisting of small particles of oxide of iron suspended in water. You can render those suspended particles polar by sending round the cylinder an electric current; and their subsequent action may be rendered evident. At present they are promiscuously strewn in the liquid. But the moment the current passes they all set their lengths parallel to a common direction. Before the current passes, the strongest beam of light can hardly struggle through the turbid medium. But the moment it passes, light is seen to flash out upon the screen. Now, if you imagine the mud of slate rocks to have been thus acted on, so as to place its particles with their lengths in a common direction, such elongated and flat particles would, when solidified, certainly produce a cleavage.

Plausible as this is, it is not the proper explanation, the cleavage of the slate rocks being demonstrably not crystalline, but, as shown by Sharpe, Sorby, Haughton, and myself, due to pressure.

The outward forms of these crystals are various and beautiful. A quartz-crystal, for example, is a six-sided prism, capped at each end by six-sided pyramids. Rock salt, with which your neighbours in Cheshire are so well acquainted, crystallises in cubes; and it can be cloven into cubes until you cease to be able to cleave further for the very smallness of the masses. Rock salt is thus proved to have three planes of cleavage at right angles to each other. Iceland spar has also three planes of cleavage, but they are oblique instead of rectangular, the crystal being, there-

fore, a rhomb instead of a cube. Various crystals, moreover, cleave with different facilities in different directions. A plane of principal cleavage exists in these crystals, and is accompanied by other planes, sometimes of equal, sometimes of unequal value as regards ease of cleavage. Heavy spar, for example, cleaves into prisms, with a rhombus or diamond-shaped figure for a base. It cleaves with greatest ease across the axis of the prism, the other two cleavages having equal values in this respect. Selenite cleaves with extreme facility in one direction, and with unequal facilities in two other directions.

Looking at these beautiful edifices and their internal structure, the pondering mind has submitted to it the question, How have these crystals been built up? What is the origin of this crystalline architecture? Without crossing the boundary of experience we can make no attempt to answer this question. We have obtained clear conceptions of polar force: we know that polar force may be resident in the molecules or smallest particles of matter—we know that by the play of this force structural arrangement is possible. What, in relation to our present question, is the natural action of a mind furnished with this knowledge? Why, it is compelled by its bias towards unity of principle to transcend experience, and endow the atoms and molecules of which these crystals are built with definite poles, whence issue attractions and repulsions for other poles. In virtue of this attraction and repulsion some poles are drawn together, some retreat from each other; atom is thus added to atom, and molecule to molecule, not boisterously or fortuitously, but silently and symmetrically, and in accordance with laws more rigid than those which guide a human builder when he places his bricks and stones together. From this play of invisible particles we see finally growing up before our eyes these exquisite structures, to which we give the name of crystals.

In the specimens hitherto placed before you the work of the atomic architect has been completed; but you shall see him at work. In the first place, however, I will take one of his most familiar edifices, and try to pull it to pieces before your eyes. For this purpose I choose ordinary ice, which is our commonest crystalline body. The agent to be employed in taking down the molecules of the ice is a beam of heat. Sent skilfully through the crystal, the beam selects certain points for attack; round about those points it works silently, taking down the crystalline edifice, and reducing to the freedom of liquidity molecules which had been rigidly locked in a firm, solid embrace. The liquefied spaces

are rendered visible by strong illumination, and throwing their magnified images on a screen. Starting from numerous points in the ice we have expanding flowers, each with six petals, growing larger and larger, and assuming, as they do so, beautifully crimped borders; showing, if I might use such terms, the pains, and skill and exquisite sense of the beautiful, displayed by nature in the formation of a common block of ice.

Here we have a process of demolition, which, however, clearly reveals the reverse process of erection. I wish, however, to show you the molecules in the act of following their architectural instincts, and building themselves together. You know how alum, and nitre, and sugar crystals are formed. The substance to be crystallised is dissolved in a liquid, and the liquid is permitted to evaporate. The solution soon becomes supersaturated, for none of the solid is carried away by evaporation; and then the molecules, no longer able to enjoy the freedom of liquidity, close together and form crystals. My object now is to make this process rapid enough to enable you to see it, and still not too rapid to be followed by the eye. For this purpose a powerful solar microscope and an intense source of light are needed. They are both here. Pouring over a clean plate of glass a solution of sal ammonia, and placing the glass on its edge, the excess of the liquid flows away, but a film clings to the glass. The beam employed to illuminate this film hastens its evaporation, and brings it rapidly into a state of supersaturation; and now you see the orderly progress of the crystallisation over the entire screen. You may produce something similar to this if you breathe upon the frost ferns which overspread your window-panes in the winter, and permit the liquid to recrystallise. It runs, as if alive, into the most beautiful forms.

In this case the crystallising force is hampered by the adhesion of the liquid to the glass; nevertheless the play of power is strikingly beautiful. In the next example our liquid will not be so much troubled by its adhesion, for we shall liberate our atoms at a distance from the surface of the glass. Sending an electric current through water, we decompose the liquid, and the bubbles of the constituent gases rise before your eyes. Sending the same current through a solution of acetate of lead, the lead is liberated and its free atoms build themselves together to crystals of marvellous beauty. They grow before you like sprouting ferns, exhibiting forms as wonderful as if they had been produced by the play of vitality itself. I have seen these things hundreds of times, but I never look at them without wonder. And, if you allow me a

moment's diversion, I would say that I have stood in the spring-time and looked upon the sprouting foliage, the grass, and the flowers, and the general joy of opening life. And in my ignorance of it all I have asked myself whether there is no power, being, or thing, in the universe whose knowledge of that of which I am so ignorant is greater than mine. I have asked myself, Can it be possible that man's knowledge is the greatest knowledge—that man's life is the highest life? My friends, the profession of that Atheism with which I am sometimes so lightly charged would, in my case, be an impossible answer to this question: only slightly preferable to that fierce and distorted Theism which I have had lately reason to know still reigns rampant in some minds as the survival of a more ferocious age.

Everywhere throughout our planet we notice this tendency of the ultimate particles of matter to run into symmetric forms. The very molecules seem instinct with a desire for union and growth. How far does this play of molecular power depend? Does it give us the movement of the sap in trees? Assuredly it does. Does it give us in ourselves the warmth of the body and the circulation of the blood, and all that thereon depend? We are here upon the edge of a battlefield which I do not intend to enter to night; from which, indeed, I have just escaped bespattered and begrimed, but without much loss of heart or hope. It only remains for me to briefly indicate the positions of the opposing hosts. From the processes of crystallisation which you have just seen you pass by almost imperceptible gradations to the lowest vegetable organisms, and from these through higher ones up to the highest. The opposition to which I have referred is: that whereas one class of thinkers regard the observed advance from the crystalline through the vegetable and animal worlds as an unbroken process of natural growth, thus grasping the world, inorganic and organic, as one vast and indissolubly connected whole, the other class suppose that the passage from the inorganic to the organic required a distinct creative act, and that to produce the different forms, both in the world of fossils and in the world of living things, creative acts were also needed. If you look abroad you will find men of equal honesty, earnestness, and intelligence, taking opposite sides as regards this question. Which are right and which are wrong is, I submit, a problem for reasonable and grave discussion, and not for anger and hard names. The question cannot be solved—it cannot even be shelved—by angry abuse. Nor can it be solved by appeals to hopes and fears—to what we lose or gain here or hereafter by joining the one or the other

side. The bribe of eternity itself, were it possible to offer it, could not prevent the human mind from closing with the truth. Scepticism is at the root of our fears. I mean that scepticism which holds that human nature, being essentially corrupt and vile, will go to ruin if the props of our conventional theology are not maintained. When I see an able, and in many respects courageous man, running to and fro upon the earth, and wringing his hands over the threatened loss of his ideals, I feel disposed to exhort him to cast out this scepticism, and to believe undoubtingly that in the mind of man we have the substratum of all ideals. We have there capacity which will as surely and infallibly respond to the utterances of a really living soul as string responds to string when the proper note is sounded. It is the function of the teacher of humanity to call forth this resonance of the human heart, and the possibility of doing so depends wholly and solely upon the fact that the conditions for its production are already there.

JOHN DALTON AND HIS ATOMIC THEORY.

A LECTURE, delivered in the Hulme Town Hall, Manchester, on Wednesday, November 4th, 1874.

BY PROFESSOR ROSCOE, F.R.S.

LADIES AND GENTLEMEN,—In the eloquent lecture which we heard last week from our friend Professor Tyndall you learnt that the old Greek philosophers established what they called an atomic theory of matter; that is to say, they supposed that matter was composed of very small indivisible particles, and these particles, they imagined, flew about amongst one another in an erratic kind of way, sometimes knocking against one another, and sometimes passing one another; and they further supposed that these atoms were armed with certain claws or hooks by which they occasionally stuck together. Professor Tyndall then informed you that long afterwards Sir Isaac Newton showed that, instead of moving at random amongst one another, these atoms were attracted one towards another according to fixed and inevitable laws. On this principle he was not only able to explain the motions of the heavenly bodies, but he thereby laid the foundation of the idea of molecular force.

I have this evening to bring before you a further step in this great question. I have to tell you—and I am afraid I shall be able to tell you but very imperfectly as compared with the eloquence of my predecessor—how our great townsman, John Dalton, applied this theory of atoms to chemistry, thereby giving a precision and exactitude to this science which had previously been altogether wanting. The science of chemistry has to do with those changes of matter which not only affect the smallest particles of matter, but which at the same time are of such a permanent character as to produce from two or more unlike bodies a

third body differing altogether from its components. Let me, by an example, make this clear to you. I have here a substance, bright, shining, and black, known as iodine. I have here another body, soft, wax-like, and inflammable, termed phosphorus. If I bring together a small piece of phosphorus and a small piece of iodine, a chemical change will take place. You observe, when I bring these two substances together, that an evolution of light and heat occurs, and the substance which is produced is altogether different from either the iodine or the phosphorus.

Now you may very well ask how it was that Sir Isaac Newton did not apply the atomic theory to chemistry, and how it came to be left for so long a period as up to the year 1803—almost within the memory of living men—before the atomic theory of chemistry was established. The reason of this lies in the fact that chemistry is a very new science, so much so indeed that chemistry as a science scarcely existed at the time of Newton. In old days, you will remember, I dare say, that four elementary bodies were said to exist, namely, earth, fire, air and water; but in later years this has been found to be an erroneous supposition; and it is now well known, as indeed it was known to Dalton, that instead of those four conditions of matter, there exist a much larger number of distinct substances with which the men of Newton's time were unacquainted, and which we now term the chemical elements. These are essentially different substances, which cannot be transformed one into the other, and out of each of which no different kind of substance can be got.

What, now, is the fundamental idea which lies at the foundation of Dalton's chemical theory of atoms? How does his theory differ from those of his predecessors? and what did he add to their theories in order to fit them for application to the science of chemistry? *The idea introduced by Dalton was the idea of weight.*

Up to his time no one had troubled himself to ask what is the weight of the atoms? or do the atoms of all these 63 elementary bodies weigh alike? These questions were, however, asked by Dalton, and the answers to these apparently simple questions are to be found in his celebrated *Atomic Theory*. In asking these questions, and in obtaining the requisite answers, John Dalton exhibited in a striking degree that power of spiritual insight into the secrets of nature which Professor Tyndall so truly describes as an essential condition of the true philosopher. It was no slight matter first to find the material which should give him an opportunity of putting such questions, and it required

a mind of the highest powers and wonderful clearness of vision to penetrate beyond the domain of sense and give a satisfactory explanation of observed phenomena by reference to atoms so minute as to be infinitely removed from our powers of observation.

Let us endeavour, if we can, to acquaint ourselves with the process by which Dalton arrived at this great idea, let us try to trace its rise from visible and experimental evidence to that hidden source from which it sprung into full and perfect stature. But before we do this, it may be well, perhaps, for me to give you some idea, however slight, of the character of the man who made this great advance in our science. Coming from a humble but thrifty north-country Quaker stock, John Dalton, like many of the greatest men of this and other countries and ages, was entirely self-made. His chief characteristics were independence of spirit, fearlessness of inquiry, clearness and straightforwardness of vision, indomitable perseverance, and entire, unselfish, and life-long devotion to the prosecution of scientific truth. Bred up amongst prosaic people, and devoid of care for the ordinary social and political interests of society (he always said he had no time to get married), and uninfluenced, partly, perhaps, from his peculiar defect of vision, colour blindness, by the beauty of nature as it affects the imagination of ordinary people, Dalton all the more enjoyed the power of grasping in his mental vision ideas and principles which were hidden from the mass of mankind.

Dalton's independence of spirit and determination of mind were shown very early. One day, when he was between eleven and twelve years of age, he posted a notice on the door of his father's weaver's cottage at Eaglesfield, near Cockermouth, where he was born (September 5, 1766), stating that he had opened a school for children, and that the village children would be taught on reasonable terms. This school he first taught in an old barn, then in his father's cottage, and afterwards in the Friends' meeting-house at Eaglesfield. As a schoolmaster he began life, and as a schoolmaster he ended it. By teaching he through life earned his bread—first in Eaglesfield, next in Kendal (where he undertook a school in conjunction with his brother), and afterwards in Manchester, first (in 1781) as a science tutor to the Manchester New College, then existing in this city, and lastly as a private tutor of mathematics and science to anybody who could afford to pay from eighteenpence to half-a-crown a lesson. This routine instruction was, however, only the outside occupation of his mind. All the time he was teaching the children at Eaglesfield, the boys at

Kendal, and the young men and young women in Manchester, his innermost powers were quite otherwise engaged; first, by solving mathematical problems, published in a magazine which was in those early days much sought after; then by the study, in Kendal, of many branches of scientific inquiry, especially those interesting meteorological phenomena which all true lovers of nature must admire; thus laying the foundation for those grand scientific discoveries which have since made his name immortal. In November, 1802, he read a paper before the Literary and Philosophical Society of Manchester—a society which boasts the names of many great men on the long roll of its members, and has done and is still doing great and good work in the encouragement and advancement of science in this country.

This paper is entitled "An Experimental Inquiry into the proportion of the several gases contained in the Atmosphere," and it is interesting to us because it contains the germ of his great work; for he found, on investigating the properties of the atmosphere, that one of its component gases—namely, oxygen—has the power of combining chemically, in two different proportions, with this colourless gas called nitric oxide, to form two distinct compounds, and that the quantities by weight of oxygen which thus combine are in the simple ratio of one to two.

Dalton likewise showed that it was impossible to get any intermediate compound between these two. The nitric oxide in the one case took up twice as much oxygen as it did in the other; and it was this circumstance which first drew John Dalton's mind to his great discovery.

The fact thus discovered by Dalton, that one chemical element or compound can combine with another chemical element in two different proportions by weight, which stand to each other in the simple ratio of one to two, was borne out by the study, in the year 1804, of two other sets of colourless gases.

Here I have two other compounds which were examined by Dalton; they are both colourless and invisible gases. One of them is termed carbonic oxide gas, and the other is termed carbonic acid gas. They both contain carbon, and they both contain oxygen.

Dalton found that this substance—carbonic acid gas—contains exactly twice as much oxygen as this carbonic oxide gas contains, and he, as before, found it to be impossible to get any intermediate compound containing anything less than double the quantity of oxygen. I will show you again that we have here two very

different substances. This body—carbonic acid—will extingu the burning candle which I introduce into it; whilst in the othe case of the carbonic oxide gas we shall find that when we bring a light to it the gas will burn with a bright blue flame.

This carbonic acid is a very heavy gas, so much so that I will show you that I can pour carbonic acid gas as if it were water into this deep beaker glass which is suspended on a balance, and, as I pour it in, I think you will notice that the beam will go down, showing that carbonic acid is a heavy gas. You see by the fact that a lighted taper is extinguished when I introduce it into the beaker, that I can pour in this gas from one vessel to another as I can pour water. On the other hand, I cannot pour this carbonic oxide gas into a vessel in like manner, as this gas is not heavier than air. Remember, then, that Dalton discovered that carbonic acid gas contains *twice as much oxygen* as carbonic oxide gas does.

I will give you a third example of this same fact, namely, that bodies exist containing the same elementary constituents—in this case carbon and hydrogen—in which the quantity of the two constituents stands in a simple relation the one to the other. Here are the other two colourless invisible gases; one of these is termed marsh gas, or fire-damp—the other is termed olefiant gas, or oil-making gas. These two bodies contain carbon and hydrogen, but this olefiant gas contains, as Dalton showed in 1804, *exactly twice as much carbon* as the marsh gas does. The marsh gas burns, as you see, with a scarcely luminous flame, but when I burn the olefiant gas, you will notice that the flame is much more luminous. Here, then, we have an important difference between these two gases.

I shall now show you that both of these gases contain carbon, and that this olefiant gas contains a great deal more carbon than the marsh gas. If I could weigh it before you, or measure it, as Dalton did, we should find that it was exactly twice as much. I have here a bottle filled with this olefiant gas, and I have here another bottle filled with a gas which is not a colourless, but a yellow gas, called chlorine. If I bring these two substances together—chlorine and olefiant gas—and then apply a light to the mixture, you will see that the colourless olefiant gas contains carbon. Now you observe a sudden flash, followed by a black smoke; and here you see the black carbon, or charcoal, which was contained in the olefiant gas. Now I will do the same with the marsh gas, and we shall not get so much carbon; we may get a little, enough,

perhaps, to show that carbon is contained in the gas, but not much more. I take another vessel of chlorine, bring the two vessels together and apply a light, and here, you see, we get some carbon, but not nearly so much as before.

Now then comes the question—How does Dalton explain this? Dalton was not satisfied with these experiments; he was not satisfied with merely ascertaining that there is twice as much carbon in the one gas as in the other, or twice as much nitrogen in the one gas as in the other. He had experimentally discovered the law of combination in multiple proportions, but he wished to go deeper into things. He wished to know *why* this was so. He wished to know why it was that one compound contained just twice as much of one constituent as the other compound did, and why we cannot produce a substance containing an intermediate quantity of the constituent. Pondering on this subject, he arrived at his atomic theory, which serves to explain the fact of what chemists now call the law of "*multiple proportions*;" that is to say, that bodies are capable of combining with one another in one proportion by weight, in twice that proportion, in three times that proportion, and so on, but in no intermediate proportion.

Dalton now said, if we suppose that atoms exist, and that by their contact they form chemical compounds, and further supposing that the atom of each elementary body has a fixed weight which differs from that of the atom of any other element, then we are able to explain why we get combinations to occur only in this proportion of one given weight, and twice that weight, or three times that weight, and so on. I must not forget to remind you that these atoms are so small that it is perfectly impossible for us ever to hope to see them; nor must I forget to refer you to an admirable and learned lecture on the nature of the atomic hypothesis given in this Hall by Professor Clifford two years ago. I may tell you that a great living physicist, Sir William Thomson, has calculated approximately—for we are as yet unable to do more—how large, or rather how small, the atoms are; and he has come to this conclusion—that if you were to take a drop of water, and magnify it up to a globe of the size of the earth, then the atom contained in that drop of water would not be so large as cricket balls, nor so small as shot pellets. This may serve to give you an idea of the minute character of the atoms of which matter is composed.

Now let us attempt to get hold of the idea present in John Dalton's mind. He argued thus: All the atoms of nitrogen have

each a certain definite unalterable weight, and we may suppose the atom to be represented by this white block. What happens, he then continues, when this atom of nitrogen combines with an atom of oxygen? When they come into contact and clash together a chemical compound is formed, a substance differing altogether both from nitrogen and from oxygen—a substance having peculiar properties of its own—a distinct chemical compound. Now, he continues, if any chemical action takes place between oxygen and nitrogen, the least quantity of each which can combine is one atom, because the atom is indivisible, and, if more nitrogen is capable of entering into combination with the substance already formed, to produce a second new substance, the smallest quantity of nitrogen which can do this is again one atom; so that, of the two compounds, one consists of one atom of oxygen and one atom of nitrogen, and the other of one atom of oxygen and two atoms of nitrogen.

Thus: $\boxed{\mathrm{N}} + \boxed{\mathrm{O}} = \boxed{\mathrm{NO}}$

And $\boxed{\mathrm{N}}\ \boxed{\mathrm{N}} + \boxed{\mathrm{O}} = \boxed{\mathrm{NNO}}$

We may build up these compounds with our cubes: here is the one and here is the other. It is now clear why we can produce no compounds intermediate between these two—we cannot divide the atom of nitrogen. It is an indivisible particle, and is, therefore, the smallest portion of nitrogen capable of entering into combination.

This, then, was Dalton's explanation of the formation of these two gases of which I have spoken.

Let us next pass on to the second case considered by Dalton of the two compounds of carbon and oxygen—carbonic oxide and carbonic acid gases. Here again we can make the matter plain to ourselves by the help of a model. This black cube represents an atom of carbon, and this red one an atom of oxygen. Now when this one atom of carbon combines with oxygen, the least quantity it can combine with is one atom, and that simplest of all combinations constitutes, according to Dalton, the first of these bodies—carbonic oxide gas. Now, continued he, the second compound—carbonic acid gas—which we know to contain twice as much oxygen as carbonic oxide—is one which is built up of one atom of carbon and of two of these red atoms of oxygen, and it is therefore clear that we cannot have any intermediate form between the two compounds, and the fact is explained that in these two

gases the proportion of oxygen is as one to two. We may next take a third illustration used by Dalton. This olefiant gas is, according to him, a compound of one atom of carbon and one atom of hydrogen. Here we can build up olefiant gas, according to Dalton's view. Marsh gas, or, as he calls it, carburetted hydrogen arising from stagnant water, on the other hand, is a compound containing twice as much hydrogen as olefiant gas, and it is therefore represented as made up of this one atom of carbon and these two of hydrogen. Here again, then, no intermediate compound is known, and Dalton's atomic theory tells us why.

I may perhaps be here allowed to remind you that this atomic explanation of the facts of combination in multiple proportions was one which could only have arisen where the conceptions are as clear as crystal, and this was a striking characteristic of Dalton's mind. Nor could this passage from the actually visible concrete masses of matter to the invisible minute atoms—a passage which seems so easy when it has once been made—have been achieved by any but a master spirit? By a process of reasoning upon the results of experiment—a process which I am afraid I cannot make clear to you to-night—Dalton was able to ascertain *the relative weights of the atoms*. He could not take a single atom and weigh it, but he could ascertain the relative weights of the atoms—that is to say the proportion which existed, for instance, between the weight of the atom of oxygen and the weight of the atom of hydrogen; and the relative weights of the atoms found in the following table are those first published by Dalton in a paper read on October 21st, 1803, but not printed until 1805.

TABLE OF THE RELATIVE WEIGHTS OF THE ULTIMATE PARTICLES OF GASEOUS AND OTHER BODIES (JOHN DALTON, 1803):—

Hydrogen	1
Azot	4·2
Carbon	4·3
Ammonia	5·2
Oxygen	5·5
Water	6·5
Phosphorus	7·2
Phosphuretted hydrogen	8·2
Nitrous gas	9·7*
Ether	9·6
Gaseous oxide of carbon	9·8
Nitrous oxide	13·9*

* Misprints of 9·3 and 13·7 occur here in the original table.

Sulphur	14·4
Nitric acid	15·2
Sulphuretted hydrogen	15·4
Carbonic acid	15·3
Alcohol	15·1
Sulphureous acid	19·9
Sulphuric acid	25·4
Carburetted hydrogen from stagnant water	6·3
Olefiant gas	5·3

A glance at this table shows us that Dalton took hydrogen, being the lightest substance known, as the unit of comparison, and he compared the weights of the ultimate particles of all the other elements and compounds with that of hydrogen taken as 1. Then he found that the atom of azot, or nitrogen as we now call it, was 4·2; that of carbon 4·3, that of oxygen 5·5, and so on. A more careful inspection of the table, especially with regard to the three sets of gases about which I have spoken, will reveal to us Dalton's views as to the constitution of these substances. Thus opposite nitrous gas—now termed nitric oxide gas—we find the figures 9·7. What do these signify? They mean that this gas is made up of one atom of nitrogen (or azot) weighing 4·2, and one atom of oxygen weighing 5·5, and that the weight of the compound atom (if we may use the term) of nitrous gas weighs 9·7. Opposite nitrous oxide we find placed 13·9; this means that the ultimate particle of this gas contains two atoms of azot weighing twice 4·2, and one atom of oxygen weighing 5·5. In like manner the gaseous oxide of carbon has the number 9·8 placed against it, viz., $4·3 + 5·5$; whilst opposite carbonic acid we find 15·3, viz., $4·3 \times 2 + 5·5$.

Thus, then, Dalton built up his atomic theory; but, in order to make this theory more manifest, Dalton was in the habit of drawing his atoms, for he had a strictly mechanical turn of mind. Here you see the mode in which Dalton pictured or symbolised his atoms. This is a drawing of Dalton's atoms, expressed by symbols: oxygen is represented by a circle with a dot in the middle, hydrogen by a simple circle, and the other elements were expressed by circles with a line or a cross drawn through or upon them. This will give you an idea of the matter-of-fact as well as speculative character of Dalton's mind, and how he made clear to himself and to the world the new notion of the existence of these elementary atoms, each one having a given unalterable weight by which the element was characterised.

You must not go away with the supposition that the numbers I have referred to, or even the composition which I have given to the gases in question, have not undergone great changes since Dalton's time. All the conclusions which Dalton drew depended upon experiment, and since his day many of his experiments have been found to be inaccurate, and, therefore, many of his conclusions have had to be remodelled. The modern tables of atomic weights which chemists now employ, contain totally different numbers for the elementary atomic weights from those originally proposed in 1803. But although the details have thus been changed, the principles upon which Dalton founded his theory remain firmly fixed, and every subsequent discovery and every subsequent investigation has only served to confirm and corroborate the truth and value of the labours of this grand old Quaker.

Of the scientific importance of this discovery there can be no question; indeed, chemistry could hardly be said to exist as a science before the establishment of the laws of combination in multiple proportions, and the subsequent progress of chemical science materially depended upon the determination of these combined proportions or atomic weights of the elements first set up by Dalton. So that amongst the founders of our science, next to the name of the great French philosopher, Lavoisier, will stand in future ages the name of John Dalton, of Manchester.

Even from a practical and business point of view, the discovery of these combining proportions is of the greatest value. Thus, for instance, in the manufacture of oil of vitriol, a substance which is required in thousands and thousands of tons every year for different industrial purposes, before John Dalton had determined how much sulphur, and how much oxygen, and how much hydrogen combine together to form this sulphuric acid or oil of vitriol, no manufacturer could tell, except by rule of thumb, how much of each particular constituent had to be brought together. It was necessary, in order that the chemical manufacturer should be able to prepare this substance economically, that he should be able to ascertain, with the greatest precision, how much sulphur he must burn, how much air he must use, and how much water he must add in order with the greatest economy to produce this product for the market. It is the same with every chemical action that occurs, and it is to John Dalton—who made his living by giving private lessons at half-a-crown each—that we owe this knowledge which has made the fortunes of thousands, because he first told us the laws which govern these chemical actions.

As showing what a clear-headed man with indomitable perseverance and entire devotion to his science may accomplish, in spite of adverse circumstances, it would be well for all of you to read, mark, and inwardly digest the life and labours of this remarkable man. You will find these labours more fully and vividly depicted than I can attempt to do to-night in a book which has recently been written by my friend Dr. Lonsdale, viz., "The Lives of the Cumberland Worthies," of whom Dr. Dalton was one of the foremost. You will there find, not only a clear and concise account of his numerous scientific discoveries, but also a lively picture of the man himself, which, I venture to think, will not soon be forgotten by those who read it.

In looking back upon John Dalton's work, it is marvellous to see with what small means he accomplished great ends. His apparatus was extremely simple, much of it home-made, and often of the rudest description. His experiments, however, were all of a quantitative character; he wanted always to use his experiments as a step to a generalisation. He was constantly on the look-out for laws, and these laws he verified by experiment. But, as read by the light of modern and more exact research, many of Dalton's experimental methods prove to be crude, and even erroneous. They, nevertheless, served their end; they led Dalton to generalise, and to set up laws the truth of which modern accurate investigation has only more fully confirmed.

The question may next naturally arise in your minds, What use have the chemists since Dalton's time made of the atomic theory; how have they enlarged it, and how have they built up their scientific edifice upon it? They have not been idle. Since Dalton's time the atomic theory has been advanced in a great many directions. We are now able to do a great deal more than he was even able to conceive in the way of building up these atoms together and making a complicated chemical edifice. We are now beginning to know something of the way in which these atoms are attached together, the way in which the chemical house, if we may so express it, is built up; and, singularly enough, we have even come back again to the old notion of certain claws or points of attachment by which the atoms are fixed together. But the foundations of this edifice were laid by John Dalton; and all that we have done is to go on building upon the lines which he laid down.

In Dalton's time chemists were able to prepare artificially but a limited number of compounds; now they are able to build up an enormous number. Then, the substances which were found in

animal and vegetable bodies were supposed to be produced by the action of life, and capable of production only by the action of life; now, many of these so-called animal and vegetable substances can be artificially prepared.

In the year 1828 a great discovery was made by a celebrated German chemist, Professor Wöhler. He found that this beautiful white substance—urea—which occurs in the animal body, and which it was supposed up to that time could only be produced by the action of life, can be built up from its inorganic constituents; for he was able to take the atoms of carbon, oxygen, nitrogen, and hydrogen, and build up this body, which had not been artificially produced before. This was the beginning of the breaking down of that barrier between organic (or animal and vegetable) substance and inorganic (or mineral) substance, which has now almost disappeared. We are now daily learning how to produce more and more of these substances which are found in or are the products of animal and vegetable life.

Up to this time chemists have gone on building, and building, and building, until liquids having the most complicated composition, and solids having the most complicated crystalline structure, have been formed. There is, however, another kind of material, termed *organised* material. I will show you, as an example of this organised or structural matter, a picture of some starch granules on the screen. Here again are some similar simple forms of organised material, the red blood corpuscles which float in the blood of all red-blooded animals. Each of these small cells has a distinct structure, which is different altogether from that of the crystalline or the liquid form of matter. The two halves of a globule, when divided, are not the same as a whole globule. Here, for the present, the synthetic or building-up power of our chemistry ends. We have not been able, and the evidence at present rather goes to show that there is not much hope of our being able, to construct these granules artificially; so that the great question of spontaneous generation, or the production of animal or vegetable life, or organised material, from inorganic sources, without the intermediation of any germ—this question, which has been so much discussed on so many occasions—is in this position, that so far as science has progressed at present, we have not been able to obtain any organism without the intervention of some sort of previously existing germ. Still we must not shut our eyes to the fact that there is still a wide field for observation and experiment yet to cover before we can regard this question as satisfactorily decided. We

are only just beginning experimentally to touch questions of this nature, and it is far too early for us to feel much confidence in any wide or general conclusion drawn from the limited experience of the present day.

Ladies and gentlemen,—I believe I have exhausted the time allotted for my subject this evening. I trust I have made clear to you the very great importance of John Dalton's discoveries; and I cannot but hope that you will hereafter not only honour his name the more, but feel a greater interest in the man and his discoveries. I would only say a word in conclusion as regards the moral which we must draw from John Dalton's life and labours. What lesson do they teach? Surely this—that in order to flourish and produce fruit, such as we have been studying, science must be free—free to experiment and observe without let or hindrance; free to draw the conclusions which may flow from such experiments or observation; free, above all, to speculate and theorise into regions removed far beyond the reach of our senses.

On the Transit of Venus.

A LECTURE, Delivered in the Hulme Town Hall, Manchester, on Wednesday, November 11th, 1874.

By WM. HUGGINS, D.C.L., LL.D., F.R.S.

I HAVE undertaken to give you to-night some account of that grand astronomical event which is to take place next month, and in the observation of which nearly all the nations of Europe and the United States of America will vie with each other in friendly rivalry. The passage of Venus between us and the sun, so as to appear to an observer on the earth as a black spot crossing the sun's face, is a phenomenon which has not taken place for more than a hundred years, and, therefore, from its rarity alone, would receive some attention. But you know that the elaborate preparations which have been in progress for the last two or three years, and the large sums of money which have been voted by the different governments, would not be justified by any appearances which will be seen at the time of the transit; because the passage of a black spot across the sun, unlike a solar eclipse, possesses no elements of unusual grandeur, and does not help us, as an eclipse does, to solve some of the most important physical problems of the universe. What we hope to gain from the well-equipped expeditions which will occupy some seventy-five stations in remote parts of the earth, is an indirect result, which will have to be worked out afterwards by a somewhat intricate process of calculation. The whole world is looking forward to the transit of Venus because we hope to learn from it with greater accuracy than we know it at present *the distance of the earth from the sun.* It appears to me, therefore, to be my duty to-night first and foremost to attempt an explanation, as simple and as popular as possible, of the principles on which the observation of a black spot crossing the face of the sun can teach us the distance of the sun from the

earth. I say the "principles," because it would be quite out of place on an occasion like the present for me to attempt to go into the details which would be necessary in a description of the exact processes which will have to be followed.

Before speaking of the transit itself I would wish to say a few words on some preliminary points; and I purpose to arrange what I have to say in the following order: First, to say something of the importance of knowing the distance of the sun from us; Second, on the methods by which we can learn the distance of objects which we cannot approach; Third, the reason why it is impossible to apply this method of parallax to the sun directly; Fourth, on some other methods by which we can learn the distance of the sun. A very brief glance at these points will prepare us for a consideration of the transit, both in respect of the mode of making the observations and of the way of utilising these observations afterwards for the determination of the sun's distance.

First, of the importance of knowing the distance of the sun. And, here allow me to ask you to try and realise the conditions of the problem. Just take the illustration which was suggested by Sir John Herschel. Suppose the sun to be represented by a globe two feet in diameter, in the centre of a large croquet ground; then, on the same scale, the earth would be represented by a pea at the distance of 215 feet. Now, imagine further that this pea is in rapid rotation, and that it is also advancing with great rapidity in its course round the central globe. Then, give the reins to your imagination, and suppose there are upon that pea microscopic living specks as much smaller than the pea as men are smaller than the earth upon which we live. And, then finally, imagine that these living specks have set to themselves the problem of determining the distance of that rotating pea from the central globe, in units of measure taken from the pea itself.

Now it is of the first importance to distinguish between the knowledge of proportional distance and of actual distance—between the knowledge of the distance of the sun, expressed in the ratio to some other distance outside the earth, as the distance of the other planets, or in the ratio of the apparent diameter of the sun itself and the actual distance of the sun expressed in units of terrestrial measure. The proportion that the distances of the different planets have to each other was known long before man was able to make even a rude guess as to the actual distance of any one of them. From observation alone Kepler, by his celebrated laws, was able to exhibit a correct plan of the Solar

System; but what was wanting was the scale expressed in units of earth measure on which the great system of the planets is built up. A glance at the diagram, to which I will point directly, will show how entirely independent a knowledge of proportional distance is of actual distance. [Dr. Huggins here, and at many subsequent parts of his lecture, referred his auditors to the diagrams on the wall. The detailed explanations are here omitted.] This shows the great importance of knowing the distance of the sun, because it becomes a standard measure, from which, by proportion, we get all the other distances and magnitudes of the heavenly bodies, with the exception of the moon. And it is in the hope of getting a more accurate knowledge of this fundamental unit that we look with so much anxiety to the observations which will be made at the beginning of next month.

This leads us to take the next step—to inquire by what method it is possible to determine the distance of a body which we cannot approach. Now the mention of the term parallax reminds me of the prose of which we read in Molière's comedy. You probably remember how delighted the "*bourgeois gentilhomme*" was to find that he had been speaking prose all his life without knowing it. And so we have been computing parallax, from our earliest years, without having any suspicion of the fact. You all know the drawing-room trick of asking anyone to snuff the wick of a candle with one eye closed. The attempt almost always fails, because the person is unable to judge of the exact distance of the candle. By asking him to close one eye we put it out of his power to estimate the parallax of the candle. Parallax is a convenient term to express the difference of position which an object has when viewed from two different standpoints. Let us see how in this way it is possible to ascertain, accurately, the distance of an object which we cannot approach. [Description of diagram to illustrate this process.]

Now, it is by the application of this method to the moon that the distance of the moon has been learned with very great accuracy. I suppose we know the distance of the moon within, perhaps, twenty miles of its actual distance; that is to say, within about one two-thousandth part of the whole distance of the moon. [Another diagram was exhibited and described.] In this way, by observations of the moon from two stations, widely distant from each other, as Greenwich and the Cape of Good Hope, the distance between these places being known, we arrive, by a very simple calculation, at the distance of the moon.

Now, we have to ask, Why is it that we cannot apply this very simple method to the sun directly, without having to go to all the expense and trouble of so roundabout a method as that of the transit of Venus? One great drawback in applying this method to the sun is the very small angle that has to be measured in the case of the sun. In the case of the sun, what one has to measure is only about one four-hundredth part as large as one has to measure in the case of the moon. But still it might be accomplished if it were not for the following circumstances. You know that whenever light passes into a medium of different density to that in which it is travelling, the path of the light is bent or broken; it is said to be refracted. Suppose that this is a ray of light, and that it falls upon a prism or a vessel containing water, then the light does not go straight, but is bent towards the base of the prism. And at the other side of the prism it is again broken, and the light is turned in another direction. Now, fortunately, the earth is not belted round with glass or water, but it is belted round with air; and air acts upon light coming into it precisely as glass or water acts upon light when entering these substances. We live at the bottom of a great aerial ocean, and we have to look at the heavenly bodies through this air, and we see them all displaced from their true positions. This would not be of so much consequence if they were all displaced uniformly, but any small alteration either in the temperature or density of the air alters the amount of this bending property, which breaks the direction of the rays of light, and hence displaces the heavenly bodies differently.

Now, when you have to observe the sun the case is very unfavourable, because, from the heat of the sun, the air is greatly disturbed, and the consequence is, that if we were to attempt to measure the parallax of the sun directly, it would be uncertain from this cause of refraction alone to about one-third of the total amount that we had to measure.

Now in the case of the moon, not only have we a much larger thing to measure, and therefore the same actual error is of less importance, being relatively 400 times less; but in the case of the moon we can get rid of refraction almost entirely, because we can observe at the same time a star quite close to the moon, both from Greenwich and the Cape of Good Hope.

Now the stars are so far off that lines drawn from them to different stations upon the earth are sensibly parallel, and hence any difference that is produced by refraction will be at once detected, and therefore can be eliminated from the observations

of the moon. Now we cannot observe stars at the same time that we can the sun, because our atmosphere is—I was going to say so very much like the air of Manchester—it is so imperfectly transparent, that it scatters so much light that the sky is always quite bright about the sun. If the air were perfectly transparent, the sky would look black up to the sun's edge; but in consequence of the scattering of light, the sky looks bright near the sun, and we cannot see the stars through this bright screen of air which interposes between them and us. For these reasons it is not possible to apply this method of parallax to the sun directly, and therefore we have to go to roundabout methods.

Now let us consider for a moment some of the other methods by which it is possible to determine the distance of the sun. Some two thousand years ago it was suggested that it would be possible from the distance of the moon to determine the distance of the sun. But unfortunately the moon is rough, and in consequence of the moon being so rough, it is not possible to tell exactly when it is half illuminated; and therefore this plan fails. Now it has been suggested and tried, from Kepler downwards, to make use of Mars. I said that for solving the problem of the scale on which the solar system is built, when we know the distance of one object, we can by a system of ratios find all the other distances. Therefore we are not obliged to take the distance of the sun as the standard; we can take the distance of some other planet, and from that find the distance of the sun. It was early suggested—I think by Kepler—that we might take the distance of Mars when it comes nearest to the earth by the method of parallax. This occurs about every eighteen years. The same diagram will represent this. We have only to suppose an observer to be at Greenwich looking at Mars, and another observer at Cape Town. He would not in that case measure the angle of Mars from the polar axis of the heavens; he would merely measure the distance of Mars from some small star near it. And then the observer at the Cape of Good Hope would measure also the distance of Mars from the same star; and the difference between these measured distances would show the small apparent shift of position of Mars, due to its being viewed from two different stations. In this way an exceedingly trustworthy determination of the sun's distance has been obtained—perhaps one of the most trustworthy that we have at the present time.

In 1862, Mr. Stone—then first assistant at Greenwich—by a comparison of observations of Mars, made at Greenwich, Cape

Town, Williamstown, and Paulkowa, found the sun's distance. The result is on that table. You will see opposite Mars the name of Stone, and he calculated the distance of the sun to be 91,240,000 miles.

Last year it was suggested by Dr. Galle, of Breslau, that advantage might be taken of some of the small planets between the orbit of Mars and the orbit of Jupiter; and he showed that at the next opposition of Flora she would be at a distance from the earth of less than nine-tenths of the sun's distance from the earth.

In consequence of this suggestion, during the past year Flora was observed at nine stations in the northern part of the earth, and at three stations in the southern part of the earth; and from a recent discussion of these observations of Flora, made precisely in the way I described with Mars, a result has been deduced by Dr. Galle very nearly the same as that derived from Mars. He gives the distance of the sun by this measurement to be 92,000,000 miles.

Another of these methods by which we may determine the distance of the earth from the sun is by availing ourselves of the perturbations of the moon. It was shown by Laplace that there is one of the perturbations in the movement of the moon which depends upon the sun's distance from the earth. I refer you to this diagram. Here is the sun, and here is the moon going round the earth. It is clear that at one point the moon is nearer to the sun than the earth is, and consequently the sun pulls the moon more strongly than he does the earth from the moon when the moon is farthest from the sun. The amount of this perturbation depends upon the ratio of the moon to the earth and the sun to the earth. By a careful examination of some 2,000 observations of the moon, Mr. Stone has found the distance of the sun to be 91,200,000 miles.

There is another way in which the distance of the sun can be deduced from the perturbation of the moon. But I pass from that to mention one other of these methods, with which is associated the name of the distinguished French astronomer, Le Verrier. The mass of the earth is so closely connected with the distance of the sun, that if we know one of them we can get the other. Le Verrier has suggested that if we can find the mass of the earth by an independent method, then from that value we can learn the distance of the sun.

There is a great advantage in this method for the reason that any error made in the sun's distance becomes threefold as great

when you deduce from it the mass of the earth; consequently, if you find the mass of the earth by an independent method, any error is diminished also in the same proportion. So that, supposing there were an error of the three-hundredth part in the finding the value of the mass of the earth, that would be reduced to an error of the one nine-hundredth part in the value of the distance of the sun deduced from it. The earth produces certain perturbations or inequalities in the motion of the two planets, Venus and Mars; and by observing the amount of these inequalities, Le Verrier is able to determine the mass of the earth independently, and from this to determine the distance of the sun; and he has found the distance to correspond very closely indeed with the other distances marked on that table, namely, 92,110,000.

Before we pass to the Transit of Venus, we must glance at a quite independent method of determining the sun's distance. You know that the planet Jupiter has four moons. These moons go round Jupiter, and to us they sometimes appear to go across Jupiter, sometimes to go behind Jupiter, and sometimes to be eclipsed by his shadow. The times of these disappearances have been calculated, and it was found that at different periods of the year the observed times differed from the calculated times. Sometimes the transits were delayed; they did not take place exactly when they ought to have taken place; the greatest loss of time exceeded sixteen minutes. Now this delay was due to the length of time that it took for light to traverse the diameter of the earth's orbit. It is quite clear, therefore, that if we could tell exactly how many miles light traverses in a minute, we could tell exactly how many miles there are in the diameter of the earth's orbit. But it may be asked—Is it possible to determine independently the velocity of light? Is it possible for the experimentalist, within the restricted space which is at his disposal upon the surface of the earth, to determine the velocity of light? You know that light will sweep round the earth eight times in a second, and therefore if the experimentalist had a laboratory 500 miles long, the light would flash from one end to the other in less than the 360th part of a second. And yet the velocity of light has been determined experimentally with the greatest accuracy, and by two different methods, both of them suggested, invented, and carried out by two Frenchmen, Fizeau and Foucault. Quite recently the method of Mons. Fizeau has been repeated, with some modifications, by Mons. Cornu of the Ecole Polytechnique. It was found by Foucault that light travels at the rate of 185,300 miles every

second. Multiply that number into the 16 minutes and some fraction which light takes to traverse the diameter of the earth's orbit, and of course half that sum is the distance of the earth from the sun, namely, 92,100,000 miles.

But there is another way in which we can take advantage of the velocity of light. You know that we have to look at all the heavenly bodies from a moving platform. The earth is constantly not only rotating on its axis but moving forward in space in its orbit; and the result of that is, if we want to look at a star, that it will not do to point the telescope exactly at the true position of the star—we must point the telescope a little in advance of it. The amount that the telescope is turned in advance of the true position depends upon the ratio of the velocity of light to the velocity of the earth in its orbit. This will be explained, I think, by this diagram. Supposing that here is a cannon, and here is a boat. If the cannon is fired at the boat, and the boat is quite still, it is obvious that the shot will enter at that red line and come out of the boat where the red line crosses it. But supposing that the boat, instead of being still, is moving forward, it is clear that the shot would come out of the boat at a different point. If you take the direction of the two holes in the latter case, it will not point at the gun, but considerably in advance of it.

Now, supposing an observer were looking at a star through a telescope: if the telescope were pointed directly at the star, then, in the time that the light takes to pass from the object-glass to the eye end of the telescope, the observer will have been carried forward by the earth's motion, and the light will not reach his eye. It is necessary for him to point the telescope so much in advance of the true position, that by the time the light has taken to traverse from the object-glass of the telescope to the eye end he may have been carried by the earth's motion into the position for that light to get into his eye. Just as when heavy rain is coming down, vertically, you hold the umbrella straight over your head if you are standing still; but, if you want to run for shelter to the other side of the road, you no longer hold the umbrella upright, but you incline it forward. Now, the amount that the telescope has to be inclined forward is known. It is found to be slightly over twenty seconds of arc. Since we know the velocity of light, it may be found, by a very simple calculation, with what velocity the earth is travelling in its orbit, namely, about 18½ miles every second. Now, the length of time the earth takes to go round its orbit is known by observation, and, therefore,

if we know how many miles the earth goes over every second, we know the length of circumference of its orbit, and, therefore, the length of the radius, or the distance of the earth from the sun. By this method the value comes out very nearly the same as in the former case, namely, 92,100,000 miles.

We have now to pass to the method of making use of the transit of Venus. Now this is a rather roundabout method of finding the distance of the sun. We have first of all to consider what it is we do know, and what it is we do not know. Now we do know the proportion of the distance of the earth from the sun to the distance of Venus from the sun. We also know the angular measure of the diameter of the sun. Those who know anything of the elements of mathematics will be aware that if you know the number of seconds in a small arc, you know how many times that arc will be repeated in the length of the radius. Therefore we know how many times the sun's diameter is repeated in the distance of the sun from the earth. What we do not know is the actual distance of the sun in miles; we only know these proportions. We are supposing that we have as yet no idea as to the actual diameter of the sun in miles; but we know that the distance of the sun from the earth is so many diameters. One way of looking at the Transit of Venus is this—that by means of noticing the position of the black spot traversing the face of the sun, from stations on the north and south of the earth, we see the shift of its position upon the sun, and so can measure a certain distance upon the sun in miles, and can say that a certain part of the sun's diameter measures so many in miles. Thus we get the whole diameter in miles, and then we have only got to multiply this by certain known proportions, and we get the sun's distance.

We must now examine the method more in detail. And first it may be asked—How is it that these transits of Venus occur so rarely? Supposing that these two circles represent the orbits of Venus and the earth, it is quite clear that if they were in one plane we should see the transit of Venus across the sun whenever Venus and the earth were in the same line. But this does not happen, and the reason is because the orbits are inclined to each other. There are therefore only two parts in the orbit where, if the two planets happen to come, Venus will be seen exactly on the sun. These points are called the nodes. If the planets are exactly in this position, Venus will cross the sun centrally; if they are not quite at the nodes, Venus will traverse a longer or shorter

chord. The transits occur either singly or in pairs at an interval of eight years after the long period of from 105½ to 122½ years. In the transit that will occur on the 8th of next month Venus will be seen to pass across the upper part of the sun. If at the time of transit the distance between Venus and the earth were the same as the distance between Venus and the sun, the space on the sun between the apparent positions of Venus as seen from two stations differing greatly in latitude would be equal in miles to the distance between these two stations; and if the stations were 6,000 miles apart, we should have that distance as a base of measurement upon the sun. But as the distance from Venus to the sun is about 2½ times the distance of Venus from the earth, instead of 6,000 miles, we have 15,000 miles mapped out for us upon the sun. We know also that these 15,000 miles mapped out for us upon the sun correspond to $\frac{1}{58}$th part of the sun's diameter. The sun's diameter, therefore, is 850,000 miles. The sun's diameter in angular measure is 31 minutes of arc. The radius is 107 times the 31 minutes; and 107, multiplied into 850,000 miles, gives us about 91,000,000 of miles for the sun's distance. To find out exactly the apparent places of Venus on the sun, as seen from the two stations, Halley suggested the observers should time the transit from the two stations. It is clear that to an observer at the south Venus will seem to go across a shorter chord, and to an observer in the north Venus will seem to traverse a longer path. From these times of duration of the transit it can be found how far the chords are apart, or the shift in the position of Venus from the difference in latitude of the stations. For this method, it is clear that the whole transit must be viewed from both stations—one as far to the north of the earth as possible, and the other as far to the south as possible. When the transit is a central one it lasts about eight and a half hours. The duration of the coming transit will be about 4¼ hours. Now there is often great difficulty in finding suitable stations at both the north and south, where the whole transit can be seen, because a large part of the earth is open water; and as these transits always occur in December and June, one part of the earth must be in winter, where the weather would be uncertain. For these reasons De Lisle suggested another way of getting at the desired result. He proposed to record at two stations either the instant of ingress, or beginning of the transit, or the instant of egress, or ending.

Let us see how we can find the sun's distance from observations of ingress or egress. [This was made clear by means of a

diagram.] It is clear that an observer at the extreme east of the earth will see the ingress earlier than an observer at the extreme west. Now during this time Venus will have passed over a certain part of her orbit. If the stations are 6,000 miles apart, Venus will have gone over 4,300 miles. The interval between ingress as seen from the two stations gives the time Venus has taken to do this. The proportion of this time to the period of Venus gives the circumference of the orbit of Venus in miles, from which we get easily the earth's distance from the sun.

There is one other way of looking at it. I must now ask you to imagine yourselves in the sun, from which standpoint you would see the earth and Venus going round, Venus moving the more swiftly. When Venus came between the sun and the earth, the shadow of Venus would pass upon the earth. As Venus would appear to move 96 minutes of arc in a day, while the earth moved only 59 minutes, the shadow would cross the earth at the rate of 37 minutes of arc in a day, that is about a second and a half in a minute. Suppose the difference of time between the ingress and the egress of the shadow on the earth to be eleven minutes, then 11 multiplied into 1″ 54′, gives 17½ seconds of arc. This angle would be that of the earth's diameter, as seen from the sun. The half of this angle would be the sun's parallax, equal to about 92,000,000 miles.

It is desirable to choose stations so that the transit shall be as short as possible at one station and as long as possible at the other, so as to diminish the influence any errors of observation have upon the result. [There were thrown on screen maps of the earth, at the beginning and the end of the transit, and the relative advantages of different stations were described.] One of the principal British stations will be at the Sandwich Islands, where the ingress will occur about twenty-one minutes earlier than at Kerguelen's Island, another of our stations. Ten minutes of this difference is due to the difference of longitude at the stations, the remaining eleven minutes to difference of latitude; in consequence of which, Venus will of course appear to enter at a different part of the sun.

The method of Delisle demands unfortunately an accurate knowledge of the longitude of the stations. The observations at each station must be referred to local time, and how can the local times of the two stations be compared unless we know accurately their longitude, or exactly how far one is east or west of the other. Here is introduced a gigantic difficulty for the independent deter-

mination of longitude with the minute accuracy required to a work of prodigious labour. To determine longitude we must somehow or other find out at the station exactly what o'clock it is at another station of which the longitude is known. If the places are near enough for signals, or are connected by telegraph, the operation is not so difficult. For more distant places recourse must be had to the transport of chronometers or to the moon. Chronometers fail if the stations are remote, as Kerguelen's Island and the Sandwich Islands. Our only resource is the moon. The moon moving among the stars may be compared to the hands of a clock moving through the figures of the dial. Now if the exact time at which the moon will arrive near any star has been calculated beforehand, then the actual arrival of the moon at that place becomes to an observer at a distant station a signal informing him of the exact time by the Greenwich clock at that instant. He looks at his local time clock, and the difference expresses his longitude east or west of Greenwich. To find the longitude to within one-tenth of a second, which is the accuracy required, will be a difficult task even for three months' work after the transit is over. There is the consideration that by the rapid increase of submarine telegraphs distant places are becoming rapidly connected, so that if from any reason the observers of any station fail to obtain a satisfactory longitude, then observations of the transit expressed in local time will not be lost, but can be utilised at any future time when the longitude of the station shall have been more accurately determined.

We have now to speak of the methods by which the observations will be made. They may be divided into three classes. First, eye observations; second, photographic records of the positions of Venus upon the sun; third, observations by the eye, aided by the spectroscope. It is clear that observations by the eye can be made only the internal contacts, for outside the sun the observer will not see Venus, and cannot have any warning of her approach. Consequently we are restricted to the moments of internal contact. I dare say it seems to you a very simple observation to fix the moment when the limb of Venus comes in contact with the limb of the sun; yet if twelve men trained to minute observation, but unaccustomed to this particular phenomenon, were to be taken, it would be found that all the twelve would give a different time for the moment of actual contact; and it is probable that they would all differ by intervals of time, greater than the interval of time which corresponds to the uncertainty in

the sun's distance. Unfortunately, a curious phenomenon presents itself just at the critical moment. As Venus comes within the limit of the sun she seems to cling to him; portions of the black sky outside the sun and portions of the black rim of the planet seem to adhere together and to be drawn out, as if Venus was made of indiarubber; and you have in this way a black patch formed between the two. As you watch this black drop it becomes thinner, until it is reduced to a thin line, and then it suddenly snaps as a piece of indiarubber might do. This is the moment that the limb of Venus is exactly in contact with the limb of the sun. I shall explain in a few moments the causes of this phenomenon; but I wish to say here that it is in consequence of the uncertainty introduced by this phenomenon into the determination of the moment of contact that a wrong distance of the sun reigned in astronomy until quite lately. The old value of the sun's distance was found by Encke in 1820, from a discussion of the results of the transits witnessed in 1761 and 1769; unfortunately, the observers had taken different phases of the drop phenomenon for the moment of contact.

A few years since Mr. Stone re-discussed the whole matter, and, by carefully studying the exact words of the different observers, he was able to attribute to each observer the particular phase of this black drop which he took for the moment of actual contact. In this way Mr. Stone found the observations much more accordant, and he brought out from them a value for the sun's distance, which was about $3\frac{1}{2}$ millions of miles less than the old value (95,000,000). The new value, about $91\frac{1}{2}$ millions of miles, agrees closely with the values of the distance as determined by the other independent methods to which I have already referred. At the present time the uncertainty lies somewhere between 8″ 85′ and 8″ 90′; and what we hope to gain from the approaching transit of Venus is to know, exactly, whereabout in this small region of remaining uncertainty the true value of the sun's distance lies. I will try to exhibit to you the "black drop." The limb of the sun is again thrown upon the screen, and Venus is now made to pass over the limb. At the moment of internal contact I expect you will see the black image of Venus drawn out and apparently clinging for a moment to the edge of the sun. Yes, there it is! Let us look at the explanation of this curious phenomenon.* Part of it is due to the telescope, part to irradiation, and part to the idiosyncrasy of the observer—some particular relation, it may be, between the eye and the brain of the individual, so that no two observers see exactly the same

phenomenon. A very bright object appears to spread over a neighbouring dark object. Here is a fine platinum wire stretched across a dark screen. I make the wire white hot; it appears to swell, and now seems several times as thick as it actually is. As it cools it seems to get thinner, and to taper to a fine point. In the same way, when Venus is upon the sun's disc the brightness of the sun spreads over Venus, and makes her look smaller. Now when Venus enters on the sun's disc. the light encroaches more and more, until the black ligament suddenly breaks at the moment of geometrical contact; but to the eye Venus seems well within the limb.

For the purpose of teaching the observers to distinguish the several phases of this phenomenon—the growth, formation, and breaking up of this chameleon-like black drop—there was erected at Greenwich an artificial transit—a black disc was made to move by clockwork over an opening in a metal plate, and light was sent through the opening by a mirror placed outside. This was observed with a telescope from a distance of 400 feet. It was found that unpractised observers differed as much as 17 seconds; but after they had been trained to observe the phenomenon, and to select a particular phase of it at the moment of true contact, they seldom differed more than one or two seconds. Similar models were set up in Russia, Germany, and France. There is no doubt that in consequence of this special form of training we shall get more accurate observations of the approaching transit of Venus than those made of the former transits.

There is another way in which the moment of actual contact may be found. You perceive that as Venus [a diagram pointed to] advances on the sun's disc, the distance between cusps diminishes rapidly with a small motion of Venus. By means of a micrometer the length of line joining cusps can be repeatedly measured. From these measures the moment of true contact may be found. With the same instrument measures of Venus from the sun's limb can be taken when she is already on his disc. A micrometer can only measure short distances. If we had an instrument by which we could measure the distance of Venus from the opposite limbs of the sun, we could find directly the distance of the centre of Venus from the sun's centre. Such an instrument is the heliometer. It is a telescope with the object glass cut in two. Each half gives its own image. Two images of the sun are seen. These are made to pass over each other by a proper screw-motion attached

to the halves of the object glass. In this way the position on Venus or the sun can be measured. Lord Lindsay has taken out one of these instruments. The Russian and German expeditions will be provided with heliometers.

We now pass to that other method of observation on which all the stations greatly depend. Though photography is, of course, free from personal bias, it has difficulties of its own. The first object is to get an image of the sun, of sufficient size, absolutely free from distortion. This will be attempted in three ways. A telescope of 4ft. focus gives an image of the sun about ½in. in diameter. This image has to be enlarged by a secondary magnified to about 4in. in diameter. Our expeditions, and those of Russia and Germany, will be provided with instruments of this form. The Americans and Lord Lindsay prefer to employ a telescope long enough to produce at once a solar image of the necessary size. Such a telescope must be 40ft. long. It is obvious that so unwieldy an instrument cannot be mounted in the usual way. The telescope will be placed horizontally, and a mirror moved by clockwork fixed before the object glass, so as to reflect the sun's light through it. The sun's image will be formed in the photographic hut, at a distance of 40ft. behind the object glass. Lord Lindsay will also employ a reflecting telescope of the Cassegrain form, by which a large image of the sun is at once formed. Two modes of working will be employed, the time-method and the position-method. For the time-method we are indebted to the French astronomer Janssen. He proposed that as soon as Venus was seen upon the sun's limb a large number of pictures should be taken at the very short intervals of one or two seconds of that part of the sun. Among this series the one representing the moment of true contact, or the pair between the taking of which true contact took place, must be found. In this way we shall get the instant of ingress or egress with an accuracy perhaps greater than that of trained eye observers. A circular photographic plate will be made to rotate by clockwork, and an instantaneous shutter will record by electric connection upon a chronograph the instant at which the pictures were taken. In addition to these time records, other photographs will be taken of Venus when on the sun. Afterwards, by means of a suitable measuring apparatus, the distance of Venus from the sun's centre can be found either directly or through the intervention of the images of fiducial wires fixed in certain positions. It has also been proposed to use the spectroscope. I stated that the external contact of Venus with the sun cannot

be utilised, because we have no warning of its approach. The sun as we see him in the heavens is not the whole of that glorious luminary. There will now be thrown upon the screen a photograph of the last eclipse of the sun in India, taken by Col. Tennant. You see there is a good deal of light from these red flames outside the sun. By means of the spectroscope these red flames can be seen at any time ; but, in the ordinary spectroscope the edge of the sun cannot be seen at the same time. Secchi, some years since, suggested an ingenious mode of combining with the ordinary spectroscope a second prism, either placed within the telescope, or over the object glass. With this arrangement it is possible to see the bright red line produced by the light of the prominences, and also the edge of the sun. We shall see Venus come along this red line, and thus be warned and be prepared to notice the exact moment of contact with the red limb of the sun. This representation will roughly explain the mode of working.

In that table you have a list of the principal British stations for observing the transit. There will be two Government stations in Egypt, and there will also be a station at Thebes, occupied by Lieut. Campbell, who has gone out on his own account. There will be a station splendidly equipped at the Mauritius, where the transit will be observed by Lord Lindsay and his assistant-astronomer, Mr. Gill. This expedition is a private one, undertaken by Lord Lindsay at his own expense. There will be other Government stations — Rodrigues, Kerguelen's Island, Christchurch (New Zealand), Australia, India, and the Sandwich Islands.

I will show you, in conclusion, a photograph of one of the little huts provided for the observers. These huts have been made in this country. They will be sent out in portions, and erected at the stations. Here you see the six-inch telescope, the clock for determining the time, and other appliances.

I will now ask you to join with me in wishing all the observers at all the stations fine weather and all possible success.

Joseph Priestley: his Life and Chemical Work.

A LECTURE, delivered in the Hulme Town Hall, Manchester, on Wednesday, November 18th, 1874.

BY PROFESSOR THORPE, F.R.S.E.

THOSE of you who read newspapers will, probably, not have forgotten that on the first of August of this present year a great gathering took place at Birmingham to do honour to Joseph Priestley, one of that band of scientific worthies which made the reign of George III. for ever memorable. On that day, Professor Huxley (than whom no one is better qualified to appreciate the whole outcome of Priestley's life, or better able to set forth the singular force and beauty of his character) uncovered a statue which the friends of science and of liberal thought had raised to the memory of the philosopher. Should there be one among you who, by any mischance, now hears of this event for the first time, let me recommend him to inwardly digest the address which Dr. Huxley then delivered: it is contained in the October number of *Macmillan's Magazine*, a periodical which, doubtless, finds a place on the tables of the library down stairs. But Birmingham was not the only town in England, nor were Englishmen the only people, that did homage to the memory of Priestley on that day. The lovers of science in Leeds, near to which place he was born, assembled in public meeting; and the chemists of America, to which country he was driven by the political and theological bigotry of his own people, met together at his grave in a quiet little town on the banks of the Susquehanna river.

My object this evening, then, is to give you some account of the labours of that philosopher, whose services in the cause of truth, and whose sacrifices in the struggle for freedom of thought, were, seventy years after his death, thus gratefully recognised.

But the very richness of my material is a source of embarrassment; for Priestley was a man of so many and such diverse acquirements—

> A man so various, that he seemed to be
> Not one, but all mankind's epitome;

his energy and the power of his application were so intense, the range of his work so wide, that the attempt to do justice to the many-sidedness of the man and of his labours would require me to inflict on you, not one lecture alone, but a whole series. You may form some conception of his marvellous mental activity, when I tell you that, as appears from the catalogue drawn up by his son after his death, he published no fewer than 108 works. Among them we have two volumes, "On the History and Present State of Discoveries relating to Vision, Light, and Colours;" next, two volumes of "Disquisitions relating to Matter and Spirit;" "A Course of Lectures on Oratory and Criticism;" "A General History of the Christian Church," in six volumes; "The Doctrine of Phlogiston Established;" "A Treatise on Civil Government;" six volumes of "Experiments on Different Kinds of Air;" "A Harmony of the Evangelists in Greek;" "A Familiar Introduction to the Theory and Practice of Perspective;" and "The Rudiments of English Grammar, Adapted to the Use of Schools." And this formidable development of the *cacoëthes scribendi* came, as he tells us, by a practice of abstracting sermons and writing much in verse.

Some particulars of the life of this extraordinary man may be interesting to you. He was born in 1733, at Fieldhead, a hamlet of some half-dozen houses, about six miles from Leeds. The old home of the Priestleys was pulled down some years ago. It was described by one who pointed out its site to me, and who remembered it well, as a little house of three small rooms, built of stone and slated with flags. By the kindness of my friend Mr. Richard Reynolds, I have been able to obtain a photograph of the place, which I will now throw upon the screen. Jonas Priestley, the father, was a cloth-dresser by trade. Of the mother but little is known beyond that she was the daughter of a farmer living near Wakefield. She died when Priestley was only seven years old, and he was taken charge of by his aunt, a Mrs. Keighley, a pious and excellent woman, in good position, but who, as he tells us, "knew no other use of wealth, or of talents of any kind, than to do good." The boy was of a weakly consumptive habit, one

consequence of which was seen in the desultory character of his early education. But his home-life with his aunt must have done much to make up for the deficiencies of his school-training. She encouraged him in his fondness for books, and as her house was the resort of all the dissenting clergymen in the district without distinction, young Priestley was constantly brought in contact with men of culture and of liberal thought, and several of them seem to have made a lasting impression on his vigorous mind. Still, the gloomy Calvinism under which he was brought up, and the frequent talk of *experiences* and of *new births* to which he listened, had its effect upon the sensitive mind in the weakly frame. Years afterwards he wrote of this period: "I felt occasionally such distress of mind as it is not in my power to describe, and which I still look back upon with horror. Notwithstanding I had nothing very material to reproach myself with, I often concluded that God had forsaken me, and that mine was like the case of Francis Spira, to whom, as he imagined, repentance and salvation were denied. In that state of mind I remember reading the account of the man in the iron cage, in 'The Pilgrim's Progress,' with the greatest perturbation." But the strengthening intellect was not slow to recover its ascendancy; and Priestley could afterwards write, in his intensely characteristic way of always looking at the sunny side of every thing and circumstance: "I even think it an advantage to me, and am truly thankful for it, that my health received the check that it did when I was young; since a muscular habit from high health, and strong spirits, are not, I think, in general accompanied with that sensibility of mind which is both favourable to piety and to speculative pursuits."

Priestley was destined by his aunt for the ministry, but her views—which were his also—were for a time interfered with by his continued ill health. Eventually he was sent to the Dissenting Academy at Daventry, which the labours of the good and learned Dr. Doddridge had brought into repute. Of the three years he spent there Priestley ever spoke with peculiar satisfaction. The system of study was congenial to his independent and inquisitive mind, for the freest inquiry on every article of theological orthodoxy and heresy was warmly encouraged, and every vexed question was in turn handled by the teachers, who took opposite sides in controversy, and incited their students to discussion. If training such as this laid the foundation of the successes of Priestley's after-life, it was also, and in no less degree,

the source of much of his misfortune. His first charge, on leaving Daventry, was at Needham Market, in Surrey; but his congregation did not like his Arianism, nor the stuttering way in which he told them of it, and they almost deserted him. Driven to extremities, he issued proposals to teach the classics and mathematics for half-a-guinea a quarter, and to board the pupils in his house for twelve guineas a year. This scheme not answering, he next turned his attention to popular science, and commenced with a course of twelve lectures on "The Use of the Globes," from which he barely got enough to pay for his globes. Although he keenly felt the effects of what he terms his "low despised situation," Priestley never lost heart or hope. He could even say of his impediment in speech, that, like St. Paul's "thorn in the flesh," it was not without its use. "Without some such check as this," he writes, "I might have been disputatious in company, or might have been seduced by the love of popular applause as a preacher; whereas my conversation and my delivery having nothing in them that was generally striking, I hope I have been more attentive to qualifications of a superior kind."

Years afterwards, however, he had his revenge; for, being invited to preach in the district when he had raised himself to some degree of notice in the world, the same people crowded to hear him; and though his elocution was not much improved, they professed to admire one of the same discourses they had formerly despised.

From Needham he passed on to Nantwich, in Cheshire, where he found himself in more congenial society, and in better circumstances, so that he was able to buy books and a few philosophical instruments. Not that philosophy here occupied the whole of his leisure, for he tells us that he betook himself to music, and learnt to play on the English flute, as the easiest instrument. Music he recommends to all studious persons; and it will be better for them, he says, if, like himself, they should have no very fine ear or exquisite taste, as by this means they will be more easily pleased, and be less apt to be offended when the performances they hear are but indifferent. In 1761 he was invited to Warrington, as "tutor in the languages" in the Dissenting Academy in that town. Here he taught Latin, Greek, Hebrew, French, and Italian; and delivered courses of lectures on Logic, on Elocution, on the Theory of Language, on Oratory and Criticism, on History and General Policy, on Civil Law, and on Anatomy. About this time, too, he made the friendship of Benjamin Franklin—a friendship which con-

stitutes a turning-point in Priestley's career, for Franklin encouraged his leaning towards philosophical pursuits, warmly recommending him to undertake his proposed History of Electricity, and furnishing him with books for the purpose. In connection with this work, he made a number of original observations in electricity, on account of which the book was favourably received; its author was made a Fellow of the Royal Society, and a Doctor of Laws of Edinburgh University. Priestley by this time was married, but seeing no prospect of providing for his family at Warrington, he accepted an invitation to take charge of a congregation in Leeds, and thither he removed in 1767. Having leisure, he redoubled his attention to experimental philosophy, and commenced that brilliant series of discoveries by which other hands and other brains than his accomplished the destruction of one of the biggest stumbling-blocks to human knowledge of which history has any record "But," writes Priestley, "the only person in Leeds who gave much attention to my experiments was Mr. Hey, a surgeon. . . . When I left Leeds he begged off me the earthen trough in which I had made all my experiments on air while I was there. It was such an one as is there commonly used for washing linen." A century, however, has changed the sentiments of Yorkshire men towards science; for they now not only show a lively interest in Priestley's work, but they have recently given evidence of a laudable desire to avail themselves of the fruit of it.

The publication by Priestley of a possible method of preventing scurvy at sea, was probably the reason of a proposal that he should accompany Captain Cook, as naturalist, in his second voyage to the South Seas. "But the appointment," says Professor Huxley, in mentioning this circumstance, "lay in the hands of the Board of Longitude, of which certain clergymen were members; and whether these worthy ecclesiastics feared that Priestley's presence among the ship's company might expose His Majesty's Sloop, *Resolution*, to the fate which aforetime befell a certain ship that went from Joppa to Tarshish; or whether they were alarmed lest a Socinian should undermine that piety which, in the days of Commodore Trunnion, so strikingly characterised sailors, does not appear; but at any rate they objected to Priestley 'on account of his religious principles,' and appointed the two Forsters, whose religious principles, if they had been known to these well-meaning but not far-sighted persons, would probably have surprised them." But the "worthy ecclesiastics," after all, did the right thing, even if they did it unwittingly; for science, as the sequel showed, was

best served by sending the Forsters to sea and keeping Priestley at home.

In 1772, Lord Shelburne desired a "literary companion," and induced Priestley to accept the office by the offer of a good salary, a house and other appointments, together with an annuity at the end of the engagement. Fortunately for science, his lordship had scarcely any duties for his literary companion to perform, and Priestley was thus able to give most of the time in which he was not engaged "in helping Providence by knocking impostures on the head," to the continuation of his chemical work. He remained with Lord Shelburne seven years: why he left him we need not inquire. Those of you who are curious on that matter will find a very probable explanation given in Dr. Huxley's address. Priestley's appearance at this period of his life is seen in the excellent statue with which Mr. Williamson has enriched Birmingham, a representation of which you see upon the screen.

Shortly after leaving Lord Shelburne, Priestley settled in Birmingham, and accepted the charge of a congregation, which he characterises as the most liberal in England. He was now nearly 60 years of age, free from embarrassment of every kind, and happy in the friendship of such men as Boulton and Watt, the engineers, Wedgwood the potter, Keir, Withering, Darwin, and the Galtons. He had ample leisure for his work, and no lack of encouragement and substantial help when needed. The picture of his life which he draws at this time indicates his serenity of mind and his sense of rest. He is thankful to that good Providence which always took more care of him than he ever took of himself, and he esteems it a singular happiness to have lived in an age and country in which he had been at full liberty both to investigate, and, by preaching and writing, to propagate religious truth. This calm, however, was but the presage of a great storm, and it burst over the old philosopher during the loud strife of party passion which agitated this country at the outbreak of the French Revolution. On the occasion of a public dinner on the anniversary of the taking of the Bastile, at which dinner Priestley was not present, and with which it does not appear that he had anything to do, a mob attacked and wrecked, in the name of "Church and King," the chapels and houses of the Dissenters in the town. The full fury of the rising seemed to be concentrated upon Priestley, and he and his family barely escaped with their lives, leaving library, papers, and instruments to the tender mercies of the

insane crowd, who, to the credit of "the age and country, speedily demolished what had been the labour and fruit of years. Priestley with difficulty got to London, but so uncertain was the temper of the time that his friends forcibly kept him in hiding for some weeks. His appeal for redress met with but a tardy acknowledgment, and the recompense which he eventually received was absurdly disproportionate to his disastrous experience of what Mr. Pitt was pleased to call "the effervescence of the public mind." His sons, disgusted with the justice which he received, left the country, and eventually settled in America. Although he himself was not without a position, for he was invited to minister to a large congregation at Hackney before he had been many months in London, and his friends vied with each other in rendering him help, his situation was still hazardous: his scientific brethren turned their backs upon him, his servants feared to remain with him, and the tradespeople declined to have his custom. At length he determined to follow his sons. Before he left he wrote these remarkable words: "I cannot refrain from repeating again, that I leave my native country with real regret, never expecting to find anywhere else society so suited to my disposition and habits, such friends as I have here (whose attachment has been more than a balance to all the abuse I have met with from others), and especially to replace one particular Christian friend, in whose absence I shall, for some time at least, find all the world a blank. Still less can I expect to resume my favourite pursuits with anything like the advantages I enjoy here. In leaving this country I also abandon a source of maintenance which I can but ill bear to lose. I can, however, truly say that I leave it without any resentment or ill will. On the contrary, I sincerely wish my countrymen all happiness; and when the time for reflection (which my absence may accelerate) shall come, they will, I am confident, do me more justice. They will be convinced that every suspicion they have been led to entertain to my disadvantage has been ill-founded, and that I have even some claim to their gratitude and esteem. In this case I shall look with satisfaction to the time when, if my life be prolonged, I may visit my friends in this country; and perhaps I may, notwithstanding my removal for the present, find a grave (as I believe is naturally the wish of every man) in the land that gave me birth." He never returned. His sons had settled at Northumberland, a little town placed in one of the most beautiful spots on the Susquehanna. Here, surrounding himself with books and taking but

little interest in the politics of the country, he occupied himself to the last with philosophy and his beloved theology; steadily refusing to become naturalized, although the expediency of such a step was requently pressed upon him, saying that "as he had been born and had lived an Englishman he would die one, let what might be the consequence."

Priestley is mainly remembered by his theological controversies and his contributions to the history of pneumatic chemistry. I have nothing to tell you of his merits as a controversialist, except to say that some of his argumentative pieces are among the most forcible and best written of his literary productions. It is on his chemical work that his reputation will ultimately rest: this will continue to hand down his name when all traces of his other labours are lost. He has frequently been styled the *Father of Pneumatic Chemistry*; and although we may question the propriety of the appellation when we call to mind the labours of Van Helmont, of Boyle, and of Hales, there is no doubt that Priestley did infinitely more to extend our knowledge of gaseous bodies than any preceding or successive investigator.

Priestley was born just as Stahl, the author of what is known in the history of chemistry as the *Phlogistic Theory*, had run out his course. To this theory, handed down as it seemed to his especial keeping, Priestley unswervingly adhered. But, by a strange perversity of fate, the very discoveries which he brought forward as the strongest proofs of the soundness of the Phlogistic doctrine have conduced, perhaps more than any other set of facts, to its destruction. Let me attempt to give you some notion of this Phlogistic Theory. A piece of wood burns: a piece of stone does not. Why is this? "Because," answers Stahl, "the wood contains a peculiar principle—the principle of inflammability: the stone does not. Coal, charcoal, wax, oil, phosphorus, sulphur—in short all combustible bodies—contain this principle in common: to this principle (which, indeed, I regard as a material substance) I give the name of *Phlogiston*. I regard all combustible bodies, therefore, as compounds, and one of their constituents is this phlogiston: the differences which we observe in combustible substances depend partly upon the proportion of the phlogiston they contain, and partly upon the nature of the other constituents. When a body burns it parts with its phlogiston; and all the phenomena of combustion—the heat, the light, and the flame—are due to the violent expulsion of that substance. This phlogiston lies at the basis of all chemical

change: all chemical reactions are so many manifestations of parts played by phlogiston.' If I strongly heat some zinc it takes fire and burns, as you see, with a beautiful greenish flame, and a white or yellowish-white substance remains behind. 'Phlogiston,' says Stahl, 'is here making its escape. Zinc is composed of phlogiston and the white earthy powder—which I term *calx* of zinc—which now becomes visible.' If I melt some lead, and keep it well stirred, it gradually becomes converted into a powder, first of a yellow and ultimately of a beautiful red colour. Phlogiston has thus been gradually expelled, its expulsion having been promoted by stirring the mass, and the calx of lead—the other constituent of the metal—becomes evident. To remake the metal, it is merely necessary to impart phlogiston to the calx, and any substance that will give up its phlogiston may be employed for that purpose. If the red lead or the calx of zinc be heated with wood or charcoal, or resin or phosphorus or sulphur, the respective metals will be regenerated. Too much of the phlogiston, however, will destroy the metallic nature of the lead or the zinc. If we employ an excess of phosphorus or sulphur (bodies very rich in phlogiston, as their excessive inflammability shows) the metals will combine with the superabundant phlogiston and lose their metallic character.

I told you that in heating the lead the calx had to begin with a yellow colour, and that it only became red by the prolonged action of the fire. The change in the colour affords a measure of the rate of the expulsion of the phlogiston. When in the yellow stage the calx has not parted with the whole of the phlogiston: as we continue to heat it more phlogiston is expelled, and the mass becomes red. So, too, if, in performing the reverse operation, we add an insufficient amount of phlogiston, the red calx is not converted into metal—it is only brought back to the yellow stage. In some such manner as this the Stahlian doctrine attempted to account for the colours of substances.

We all know that if a candle is burnt in a limited amount of air the flame will shortly be extinguished, although no change apparently takes place in the air. This was explained, according to Stahl's doctrine, by supposing that air had an affinity for phlogiston, and that in the act of combustion the phlogiston was transferred from the candle to the air. Gradually, however, the limited amount of air becomes saturated with phlogiston—that is wholly phlogisticated—and combustion accordingly ceases. In like manner, if a mouse is placed in a confined volume of air, after a

time it experiences difficulty in breathing and eventually is suffocated, although the bulk of the air remains the same. The act of breathing, therefore, is nothing else than the transference of phlogiston from the animal to the air, which gradually becomes phlogisticated and is thereby unable to support respiration. To this doctrine of phlogiston, originally broached as a theory of combustion and gradually extended into a theory of chemistry, nearly every European chemist for upwards of half a century after its author's death gave an implicit adherence.

The accident of living near a brewery whilst at Leeds first directed Priestley's attention to chemical matters. He had read of *fixed air*, the gas which we now style carbon dioxide or carbonic acid; and being desirous of making himself acquainted with its properties, he took advantage of the fermentative process in which it is abundantly formed to procure some. Priestley at this time had little or no knowledge of chemistry; he was possessed of no apparatus, and had scarcely the means of procuring any. But these very circumstances were the sources of his success, since he was under the necessity of devising original processes and appliances suited to his narrow means and peculiar views. "If," he says, "I had been previously accustomed to the usual chemical processes I should not have so easily thought of any other, and without new modes of operation I should hardly have discovered anything materially new." One of the earliest pieces of apparatus which he devised is the well-known *pneumatic trough*—a simple enough piece of chemical furniture certainly, but one that required a considerable amount of experimenting with before it took its present shape. In his experiments with fixed air he observed that this gas conferred "a pleasant acidulous taste" on water, so that he was able in two or three minutes to make a "glass of exceedingly pleasant sparkling water which could hardly be distinguished from very good Pyrmont, or rather seltzer-water." He likewise observed that "the pressure of the atmosphere assists very considerably in keeping fixed air confined in water. . . . I do not doubt, therefore, but that, by the help of a condensing engine, water might be much more highly impregnated with the virtues of the Pyrmont spring; and it would not be difficult to contrive a method of doing it." Priestley here throws out the idea of the manufacture of "soda-water"—"a service," says Mr. Huxley, "to naturally, and still more to artificially, thirsty souls, which those whose parched throats and hot heads are cooled by morning draughts of that beverage, cannot too gratefully acknowledge."

Priestley was next attracted by the singular properties of hydrogen, or *inflammable air*, as it was then termed—a gas which had already been made the subject of an elaborate memoir by Mr. Cavendish. Cavendish was inclined to suppose that inflammable air was phlogiston in the free state—an opinion contrary to the belief of Stahl and his immediate followers, who imagined that phlogiston was a solid earthy volatile substance. In order to get some clue as to the nature of this protean body, Priestley placed a quantity of minium, or the *calx of lead*—that is, lead from which the phlogiston has been expelled—within a tall cylinder, filled with inflammable air, and standing over water. He then proceeded to heat the calx by means of a burning lens—a method which he constantly employed, and which materially assisted him to many of his discoveries. Let us give the result in his own words: "As soon as the minium was dry, by means of the heat thrown upon it, I observed that it became black, and then ran in the form of perfect lead; at the same time that the air diminished at a great rate, the water ascending within the receiver. I viewed this process with the most eager and pleasing expectation of the result, having at that time no fixed opinion on the subject; and therefore I could not tell except by actual trial whether the air was decomposing in the process, so that some other kind of air would be left, or whether it would be absorbed *in toto*. The former I thought the more probable, as if there was any such thing as phlogiston, inflammable air, I imagined, consisted of it and something else. However, I was then satisfied that it would be in my power to determine, in a very satisfactory manner, whether the phlogiston in inflammable air had any *base* or not; and if it had, what that base was. For, seeing the metal to be actually revived, and that in a considerable quantity, at the same time that the air was diminished, I could not doubt but that the calx was actually imbibing something from the air; and from its effects in making the calx into metal, it could be no other than that to which chemists had unanimously given the name of *phlogiston*."

This experiment he repeated with every precaution, and in every conceivable manner— varying the nature of the calx, sometimes taking the calx of tin, of bismuth, of mercury, of silver, of iron, and of copper—and sometimes making the experiment over quicksilver instead of water. He found that the inflammable air was totally absorbed; and, accordingly, he concludes—"that phlogiston is the same thing as inflammable air, and is contained in a combined state in metals, just as fixed air is contained

in chalk and other calcareous substances: both being equally capable of being expelled again in the form of air." [The apparent absorption of hydrogen by oxide of copper when heated was shown by experiment.]

Priestley then proceeded to determine the amount of the phlogiston which must be contained in the various metals, by ascertaining the quantity of inflammable air taken up by their calces. He found that 1 oz. of lead was revived by the absorption of 108 oz. measures of inflammable air, and 1 oz. of tin by the absorption of 377 oz. measures. Let me direct your attention for a moment to these numbers, since they afford us a ready means of determining the degree of accuracy with which Priestley made his observations. The 108 oz. measures of hydrogen required to revive the 1 oz. of lead are equivalent to 204·1 cubic inches, and weigh, at the ordinary temperature, about 4·4 grains. Now, the most refined processes of modern chemical analysis have shown that the weight of hydrogen required to regenerate 1 oz. of lead from the yellow calx is 4·6 grains—no great disparity, after all, from Priestley's result. The 377 oz. measures of hydrogen required to revive 1 oz. of tin would weigh about 15·4 grains; modern chemistry says that the exact quantity needed is 16·3 grains. Priestley was here on the verge of a great discovery—a discovery which, in the first place, would have given a crushing blow to Stahl's doctrine—and which, in the second, might have ended in the determination of a fact of no less magnitude than the true composition of water. But his phlogistic ideas rendered him blind to the full significance of his results. He was prepossessed with the notion that by phlogisticating the calx, it gained in weight, and that the weight of the metal formed must be equal to the weight of the calx *plus* that of the phlogiston absorbed. He tells us that he frequently attempted to ascertain the weight of the inflammable air in the calx, "so as to prove that it had acquired an addition of weight by being metallized," but the result never came out in accordance with the theory. This, he satisfies himself, must be due to part of the calx subliming, and part being dissolved by the mercury; and he concludes, "That were it possible to procure a perfect calx, no part of which should be sublimed and dispersed by the heat necessary to be made use of in the process, I should not doubt but that the quantity of inflammable air imbibed by it would sufficiently add to its weight." Every sound phlogistian for at least a quarter of a century after Stahl's death believed that when a metal was calcined the calx *must* weigh less than the metal:

for had not phlogiston been expelled? There were indeed certain vague rumours that various people had found it otherwise: Boyle had made some experiments with tin; a French surgeon named Rey had experimented upon lead; and an obscure alchemist called Sulzbach had recorded some observations upon mercury; but then these people had not had the good fortune to work in the light of the phlogistic doctrine, or they were sceptics who were justly punished for their unbelief by their false results. But, about Priestley's time, it gradually dawned upon the phlogistians that the sceptics and ignorant people might be right after all, for some of their own trusted number had condescended to repeat the experiments which so obstinately refused to chime in with the established order of things, and found, doubtless to their dismay, that it could no longer be gainsayed that a metal by calcination *gained* in weight. But the phlogistians were not going to see their beautiful superstructure—their card-house of a theory in which all the parts seemed to fit so nicely—brought ignominiously down by the trivial weight of such a fact as this. We concede, said they, that we have been in error respecting the precise nature of phlogiston: it cannot be the gross earthy substance that Stahl had taught us to believe in. It is plainly something far more etherialised—a sort of invisible, imponderable ether—the very *principle of levity*, in fact, a principle so very light that so far from adding to the weight of bodies with which it combines, it actually makes them lighter than they were before! It seems scarcely credible, but this was precisely the position taken up by a large section of the phlogistians; not by all of them, however, for some were sagacious enough to see that a theory which needed an hypothesis of this character to bolster it up must be rapidly on the wane. "Of late," writes Priestley, "it has been the opinion of many celebrated chemists, Mr. Lavoisier among others, that the whole doctrine of phlogiston is founded on mistake. The arguments in favour of this opinion, especially those which are drawn from the experiments Mr. Lavoisier made on mercury,* are so specious that I own I was myself much inclined to adopt it." And Priestley assuredly would have adopted it if he could only have looked at the results of his experiments otherwise than through the fogs of his prejudices. He would have grasped the fact that with the disappearance of ponderable inflammable air (for light as it is it could not have been the principle of levity),

*A repetition of the experiments of Sulzbach.

the calx *lost* weight, and by much more than the weight of the inflammable air. This fact once properly laid hold of might have explained the origin of that water which he distinctly noted as being produced in his trials over mercury. In one of his experiments he heated a quantity of the calx of mercury in inflammable air, and although, as he tells us, "the gas was previously well dried with fixed ammoniac," water was found in sufficient quantity. "This experiment," he goes on to say, "may be thought to be favourable to the hypothesis of water being composed of fixed and imflammable air: as all water was carefully excluded, and yet a sufficient quantity was found in the process." But to the notion of the compound nature of water he attaches no weight. The water he supposes came either from the calx or, which he thinks more probable, from the inflammable air—that it was in fact essential to the constitution of the gas; an opinion which became a conviction when he observed how frequently water was formed in processes in which the inflammable air played a part.

When steam is driven through a red-hot iron tube inflammable air, the phlogiston of Priestley and Cavendish, is produced in abundance—a fact first observed by Lavoisier; but then, as Priestley says, "Mr. Lavoisier is well known to maintain that there is no such thing as what has been called *phlogiston*; affirming inflammable air to be nothing else but one of the elements or constituent parts of water. As to myself, I was a long time of opinion that his conclusion was just, and that the inflammable air was really furnished by the water being decomposed in the process. But though I continued to be of this opinion for some time, the frequent repetition of the experiments, with the light which Mr. Watt's observations threw upon them, satisfied me, at length, that the inflammable air came from the iron." The arrangement which Priestley made use of in these experiments is identical with that which we use on our lecture tables to-day for the same purpose. Steam is driven through an iron tube heated to redness, and the inflammable air is collected in one of Priestley's pneumatic troughs. "Of the many experiments which I made with iron," says Priestley, "I shall content myself with reciting the following results. With the addition of 267 grains to a quantity of iron, and the loss of 336 grains of water, I procured 840 ounce measures of inflammable air; and with the addition of 140 grains to another quantity of iron, and the consumption of 254 grains of water, I got 420 ounce measures of air." These numbers again serve to test the accuracy of

Priestley's work. In the first experiment the iron gained 267 grains, and the yield of inflammable air was 840 ounce measures. 840 ounce measures of hydrogen, at the ordinary temperature, weigh 34·3 grains; that is, the gain of the iron was $7\frac{3}{4}$ times the weight of the inflammable air. Assuming, then, with Lavoisier, that water is a compound, and that one constituent is fixed by the iron, and the other makes its escape as inflammable air, it would follow from Priestley's experiment that water is composed of $7\frac{3}{4}$ parts by weight of the substance fixed by iron, united to one part by weight of inflammable air. Modern science has completely established the correctness of Lavoisier's opinion, and disproved that of Priestley, but it has added little, even with all its elaborate processes of quantitative analysis, to the results of Priestley's trials. Water is composed of oxygen—the substance fixed by the iron—and inflammable air, or hydrogen; and the proportion, by weight, of the former gas to the latter, is exactly as eight to one.

Acting upon some remarks by Mr. Cavendish, Priestley was led to try the behaviour of aqua fortis, or "nitrous acid," as it was then called, upon the metals. Trying first upon brass, and then upon copper, he obtained a gas to which he gave the name of *nitrous air*, but which is now called *nitrogen dioxide.* "One of the most conspicuous properties of this kind of air is the great diminution of any quantity of common air with which it is mixed, attended with a turbid red, or deep orange colour, and a considerable heat. . The diminution of a mixture of this and common air is not an equal diminution of both the kinds . . . . but of one-fourth of the common air, and as much of the nitrous air as is necessary to produce that effect. . . I hardly know any experiment that is more adapted to amaze and surprise than this is, which exhibits a quantity of air, which, as it were, devours a quantity of another kind of air half as large as itself, and yet is so far from gaining any addition to its bulk, that it is considerably diminished by it. [This property of nitric oxide was shown by experiment.] It is exceedingly remarkable that this effervescence and diminution, occasioned by the mixture of nitrous air, is peculiar to common air, *or air fit for respiration*, and, as far as I can judge from a great number of observations, is at least very nearly, if not exactly, in proportion to its fitness for this purpose; so that by this means the goodness of air may be distinguished much more accurately than it can be done by putting mice, or any other animals, to breathe in it." Upon this principle Priestley devised a method of measuring the quality of air. A

small phial termed the *air measure*, about an ounce in capacity, is filled with the air to be examined, which is then transferred into a jar about 1½ inches in diameter, previously filled with water. The air measure is then filled with the nitrous air and emptied into the jar containing the air to be analysed. The mixture is allowed to stand for about two minutes, and is then transferred into a glass tube about two feet long and one-third of an inch wide, graduated according to the air measure, and divided into tenths and hundredth parts. The volume of the residual gas is then read off, care being taken to immerse the tube to such a depth in the trough that the water in the inside and on the outside are on the same level. The result is expressed in measures and parts of a measure: thus, if on mixing equal volumes of common air and nitrous air the residual volume is one measure and two-tenths of a measure, the standard of the air is said to be 1·2. [An analysis of the air of the lecture room was then made by Priestley's method, in the manner described].

With this instrument Priestley attempted to measure the difference between good air and that which was reputed to be unwholesome; but, although he compared the worst air he could get from manufactories, from coalpits, and from the holds of ships, with the best country air, he was unable to perceive any difference; and he was satisfied, therefore, "that air may be very offensive to the nostrils, probably hurtful to the lungs (and, perhaps, also in consequence of the presence of phlogistic matter in it), without the phlogiston being so far *incorporated with it* as to be discoverable by the mixture of nitrous air. . . . I have frequently taken the open air in the most exposed places in the country, at *different times of the year* and in different states of the *weather*, &c., but never found the difference so great as the inaccuracy arising from the method of making the trial might easily amount to or excel." Other experimenters, less conscientious than Priestley, found the differences they sought for; but the researches of Bunsen, of Regnault, and of Dr. Angus Smith, made with all the precision of modern gasometric analysis, have shown that the atmosphere is wonderfully constant in composition, and that, although there are variations, they are infinitely beyond the cognisance of the nitrous air test.

A second observation by Mr. Cavendish led Priestley to another discovery. Cavendish, in the course of the work on inflammable air to which I have alluded, attempted to prepare that gas by acting on copper with spirit of salt, or "marine acid," as it was then commonly called. Instead of the wished-for result, he

procured "a much more remarkable kind of air, viz., one that lost its elasticity by coming in contact with water." By substituting quicksilver for water in his trough, Priestley obtained this air in quantity, and examined its properties. He quickly found that the copper played no part in the process of making the gas, for on heating the acid alone he procured it just as readily. "So that," he says, "this remarkable kind of air is, in fact, nothing more than the vapour, or fumes of spirit of salt, which appear to be of such a nature that they are not liable to be condensed by cold, like the vapour of water and other fluids; and therefore may be very properly called an *acid air*, or more restrictively, the *marine acid air*." Spirit of salt, or, as chemists also term it, hydrochloric acid, is therefore nothing else than a solution of Priestley's marine acid air in water. [The rapidity with which this gas dissolves in water was shown by experiment.]

This discovery induced Priestley to try the same experiment with other acids, and, among them, with oil of vitriol. But he says, "I got no air from the oil of vitriol by any application of heat. But in attempting to procure it, I got it by means of *mercury* in a manner that I little expected, and I paid pretty dearly for the discovery it occasioned. Despairing to get any air from the longer application of my candles, I withdrew them; but before I could disengage the phial from the vessel of quicksilver, a little of it passed through the tube into the hot acid, when instantly it was all filled with dense white fumes, a prodigious quantity of air was generated, the tube through which it was transmitted was broken into many pieces (I suppose by the heat that was suddenly produced), and part of the hot acid being spilled upon my hand burned it terribly, so that the effect of it is visible to this day. The inside of the phial was coated with a white saline substance, and the smell that issued from it was extremely suffocating. . . . Not discouraged by the disagreeable accident above mentioned, the next day I put a little quicksilver into the phial along with the oil of vitriol, when, before it was boiling hot, air issued plentifully from it." The new gas with which Priestley was rewarded for his pain and perseverance he termed *vitriolic acid air*: it is now known as sulphur dioxide, and is precisely the same substance which is produced on burning brimstone in the air. You have doubtless all noticed its formation on striking a lucifer match. [The production of this gas by burning sulphur in oxygen was then shown.]

I daresay many of you have seen the beautiful etchings made upon glass by means of *hydrofluoric acid*—an acid first obtained

by a contemporary of Priestley, named Scheele—a poor Swedish apothecary, and one of the greatest chemists of the last century. Glass, as you are doubtless aware, is a mixture of sand or silica, lime, alkali, and occasionally red lead. The hydrofluoric acid acts upon the glass by seizing upon the silica and forming with it a gaseous substance termed by chemists *fluoride of silicon*. This fluoride of silicon was obtained by Priestley by heating a mixture of fluor spar or Derbyshire spar with oil of vitriol in a glass vessel. When this gas (which he termed *fluor acid air*) is led into water it is instantly decomposed, and silica is reproduced. The formation of this silica constitutes a very striking experiment; so much so, that, says Priestley, "I have met with few persons who are soon weary of looking at it, and some could sit by it almost a whole hour and be agreeably amused all the time." [The decomposition of this gas by water was exhibited on the screen.]

I doubt not that you are all familiar with that pungent, tear-exciting liquid termed by the apothecaries "spirits of hartshorn," or ammonia. This substance has been known for a very long time: its name, "ammonia," is derived from the circumstance that it was prepared, ages ago, by the Arabs in the desert near the temple of Jupiter Ammon. Now, although this liquid has been known for I don't know how many thousand years, it required Priestley to tell us that its peculiar properties were due to a gas held in solution. Priestley treated the spirit of hartshorn as he had treated the spirit of salt, and he presently found that a great quantity of a transparent and permanent air was discharged from it. He ascertained all the more striking attributes of this "alkaline air," as he termed it; among others, its solubility in water and its inflammability. [These properties were shown by experiment.] He next proceeded to determine the composition of this alkaline air by passing electric sparks through it, and he found that, after passing the sparks until no further increase of bulk could be observed, the gas was ultimately trebled in volume, and that no part of it was soluble in water. The gas, in fact, had been decomposed into its constituents—into hydrogen (the presence of which Priestley recognised), and into nitrogen, which he calls phlogisticated air, and which, he says, is contained to the extent of one-fourth of the bulk of the mixture. He then tried the action of the alkaline air upon the airs which he had previously discovered, and notably upon the "marine acid air," as he had "a notion that these two airs, being of opposite natures, might compose a *neutral air*, and perhaps the

very same thing with common air. But the moment that these two kinds of air came into contact a beautiful white cloud was formed, and there appeared to be formed a solid *white salt*, which was found to be the common *sal ammoniac*, or the marine acid united to the volatile alkali." [Experiment shown.]

If by some evil chance the cold and damp of this coming winter should drive some of you to the dentist, and if after seating you in that awful chair and harrowing your distracted nerves with the sight of his murderous tools, he humanely offers to send you to sleep with his nitrous oxide, by all means let him, and, when you wake with the sweet consciousness that "it is all over," give a passing benediction to the memory of Priestley, for he first told us of the existence of that gas.

If, too, as you draw up to the fire "betwixt the gloaming and the mirk" of these dull, cold November days, and note the little blue flame playing round the red-hot coals, think kindly of Priestley, for he first told us of the nature of that flame, when in the exile to which our forefathers drove him.

But it is quite impossible at this late hour of the night to attempt to tell you of all that Priestley did. The crowning work of his life was the discovery of that gas which he termed *dephlogisticated air*, but to which Lavoisier, who swept away all the jargon of the Phlogistic doctrine, gave the name of Oxygen. The manner of this discovery is characteristic of much of Priestley's work. "It furnishes," he says, "a striking illustration of the truth of a remark which I have more than once made in my philosophical writings, and which can hardly be too often repeated, as it tends greatly to encourage philosophical investigations; viz., that more is owing to what we call *chance*, that is, philosophically speaking, to the observation of *events arising from unknown causes*, than to any proper *design* or preconceived *theory* in this business." The accident of possessing a burning glass "of considerable force" led Priestley to try the effect of the heat of the sun upon various substances contained in tubes filled with mercury, and standing over the mercurial trough. "With this apparatus, after a variety of other experiments, an account of which will be found in its proper place, on the 1st of August, 1774, I endeavoured to extract air from *mercurus calcinatus per se*, that is, calx of mercury, and I presently found that, by means of this lens, air was expelled from it very readily. Having got about three or four times as much as the bulk of my materials, I admitted water to it, and found that it was not im-

bibed by it. But what surprised me more than I can well express was, that a candle burned in this air with a remarkably vigorous flame, very much like that enlarged flame with which a candle burns in nitrous gas exposed to iron or liver of sulphur [that is, his nitrous oxide gas]; but as I had got nothing like this remarkable appearance from any kind of air besides this particular modification of nitrous air, and I knew no nitrous air was used in the preparation of *mercurius calcinatus*, I was utterly at a loss how to account for it." His astonishment was still further increased when he found that, tested with his nitrous air, the new gas was actually better than common air, and that mice would live longer in it than in an equal bulk of that air. He had the curiosity to breathe it himself. "The feeling of it to my lungs was not sensibly different from that of common air; but I fancied that my breast felt peculiarly light and easy for some time afterwards. Who can tell but that in time this pure air may become a fashionable article in luxury? Hitherto only two mice and myself have had the privilege of breathing it. . . . But, perhaps, we may also infer from these experiments, that though pure dephlogisticated air might be very useful as a *medicine*, it might not be so proper for us in the usual healthy state of the body; for, as a candle burns out much faster in dephlogisticated than in common air, so we might, as may be said, *live out too fast*, and the animal powers be too soon exhausted in this pure kind of air. A moralist, at least, may say, that the air which nature has provided for us is as good as we deserve."

Priestley at length got to the conclusion that common air was no longer a "*simple elementary substance*, indestructible and unalterable," but a composition of 1 volume of his new air and 4 volumes of phlogisticated air. This new air, he concluded, was devoid of phlogiston—hence the term "dephlogisticated air," but that in the processes of respiration and combustion phlogiston was imparted to it. Priestley found that he could obtain this air from the calx of lead as well as from the calx of mercury, and this fact, he says, "confirmed me more in my suspicion that the *mercurius calcinatus* must have got the property of yielding this kind of air from the atmosphere, the process by which that preparation, and this of red lead is made, being similar. As I never make the least secret of anything that I observe, I mentioned this experiment also, as well as those with the *mercurius calcinatus*, to all my philosophical acquaintances at Paris and elsewhere, having no idea at that time to what these remarkable facts would lead." The knowledge

which Priestley, as he tells us, imparted to the French chemists was used by them with crushing effect against his favourite theory. The discovery of oxygen was the deathblow to phlogiston. Here was the thing which had been groped for for years, and which many men had even stumbled over in the searching, but had never grasped. Priestley indeed grasped it, but he failed to see the magnitude and true importance of what he had found. It was far otherwise with Lavoisier. He at once recognised in Priestley's new air the one fact needed to complete the overthrow of Stahl's doctrine; and now every stronghold of phlogistonism was in turn made to yield. Priestley, however, never surrendered, even when every phlogistian but he had given up the fight or gone over to the enemy. When age compelled him to leave his laboratory he continued to serve the old cause in his study, and almost his last publication was his "Doctrine of Phlogiston Established." His own life, indeed, affords an exemplification of the truth of his own words, that "we may take a maxim so strongly for granted, that the plainest evidence of sense will not entirely change, and often hardly modify, our persuasions; and the more ingenious a man is, the more effectually he is entangled in his errors, his ingenuity only helping him to deceive himself by evading the force of truth."

The Geographical Distribution of Mammals.

A LECTURE, Delivered in the Hulme Town Hall, Manchester, on Wednesday, November 25th, 1874.

By P. L. SCLATER, Esq., M.A., F.R.S.,

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ANIMALS and plants of various sorts and kinds are found all over the surface of the globe which we inhabit, from the poles to the equator, and from the lowest valleys to far above the snow-limit of the highest mountains. The rivers, lakes, and oceans that cover a large portion of the earth's surface are likewise replete with life. Recent discoveries have shown that even the profoundest depths of the Atlantic, formerly supposed to be utterly void of organic life, are tenanted by numerous forms of living beings. Now, these multitudes of plants and animals are not scattered broadcast over the earth's surface, as the casual observer might suppose; nor do they vary according to the modifications of climate or of any other set of external circumstances, as an unlearned person might well imagine. But they are distributed strictly according to certain natural laws, concerning our present knowledge of which—more especially as regards one class of animals, that of Mammals—I have to speak to you on the present occasion.

Before, however, I begin to treat of the geographical distribution of Mammals specially, I must say a few words as to what we know generally of the manner in which living organisms, whether plants or animals, are arranged over the world which we inhabit.

Let us take two distant parts of the world—England and New South Wales for example, and study their natural productions respectively. The "Fauna" and "Flora," as the sums of the animal and vegetable life are called, of these two countries, when compared together, are found to be almost entirely different. On

examining the indigenous animals and plants found in the vicinity of London, and comparing them with those observed in the neighbourhood of Sydney, or of any other part of Australia, the naturalist will find them to be utterly dissimilar. Instead of foxes and hares, the woods are tenanted by kangaroos. In place of squirrels, opossums climb about the trees Instead of sparrows and thrushes, parrots and honeyeaters abound. So likewise the snakes, frogs, insects, snails, and plants met with during a walk in the Australian bush would be quite different from the corresponding objects met with in the neighbourhood of this city. But let our roving naturalist shift his quarters from Australia half-way home towards England, and make a similar investigation in the neighbourhood of Calcutta. Here in India he will still find the animals and plants very different from those of his native shores, although not so different as those of Sydney. If he approaches still nearer—say to Egypt, there will be a much greater resemblance between the two floras and faunas; and finally, when he reaches Paris, the animal and vegetable productions, when compared with those of Middlesex, will be found to be almost, although not quite, identical.

But it will be said that these variations in animal and vegetable life may be attributable to climate. That this, however, is not the case, is at once shown by the comparison of the natural products of far-distant places of which the climate is as nearly as possible similar. Take, for example, three spots under the equator—in America, Africa, and Asia. Their faunas and floras will be found to be completely different; so much so, that a single insect, a single bird, or a single plant, out of a collection made in one of them, would usually enable the naturalist to say at a glance from which of the three spots it had been procured. Again, take the two polar extremities of the earth, of which the climates are nearly similar. Their natural products are utterly different. At the North Pole we meet with ice-bears, seals, and awks; at the South Pole, sea-lions, sea-leopards, and penguins. It is, therefore, manifest, and has been clearly shown by naturalists, that differences in the animals and plants of different countries cannot be accounted for by climate. At the same time, there can be no question that certain groups of animals specially affect particular climates, and are only found where these prevail.

The process of comparison of the organic beings of far and near countries may be (and has been) carried on to any extent, and the result arrived at has been the discovery of the following general

law—which, however, like most general laws, admits of exceptions: *That the more distant countries are, the more dissimilar are their animals and plants; and the nearer they are, the more similar are their animals and plants.*

So certain, indeed, has the law been found to be of adjoining countries producing similar or nearly similar animals and plants, that the converse of this proposition is now generally accepted by naturalists—namely, *that if the animals and plants of two countries are alike, they must either now be or recently have been in geographical connection.*

I will point out a few instances on the map of the way in which this argument has been used.

(1) The Antilles, or West India Islands, have in many respects a peculiar fauna; that is, contain a certain number of animals not known to occur elsewhere. But in Trinidad—the most remote of them—these animals do not occur, but another set, the same as those of Venezuela, are found. It is therefore evident, if the last proposition put before you be true, that Trinidad is merely a little bit of the South American continent, broken off at a comparatively recent epoch. And this, I believe, has also been shown to be the case from an examination of its geological structure.

(2) In the same way we know that the animals and plants of the British Islands are identical, or very nearly so, with those of the rest of Northern Europe. And we conclude therefore, as is likewise manifest from geological investigations, that the Straits of Dover are of comparatively recent formation.

(3) A third well-known instance is afforded by the islands of Sumatra, Java, and Borneo. Java is much nearer to Sumatra than Borneo. But the animals of Sumatra and Borneo are very nearly alike, whereas those of Java are in many cases different. It has been argued, therefore, and will no doubt be ultimately found to have been the case, that Sumatra has been joined to Borneo more recently than to Java.

But in comparing the animals and plants of two countries, it is not only necessary to ascertain, in such cases as these and others, merely whether they agree or differ—we must know exactly how far and to what degree they are like or unlike. To this end it is necessary to understand the mode of estimation of the similarities of animals (for we will in future speak only of animals, although plants follow nearly the same laws) which is usually employed by Naturalists.

conThe aggregation of all the similar individuals of any one animal

that now live, or that have recently lived in the world, is called a "species." Thus, when we speak of "The Lion," or *Felis leo*—as a scientific naturalist would call it—we understand by that term, not one particular lion, but all the lions that have lately lived, or now do live, on the earth's surface, or lion-kind in general, just as by the term mankind we mean men (and *women*) in general.

The lion *(Felis leo)* has a particular structure, shape, and colour, which distinguish it from all other kinds of cats, and, indeed, from all other known animals. This particular structure, shape, and colour, constitute what are called its "specific" characters, or marks by which any lion may be distinguished from a tiger, or a leopard, or any other animal. But, besides these specific characters, the species lion *(Felis leo)* possesses another important attribute, namely, that of being found in a natural state only within a certain limited part of the world's surface. Over this district are distributed, in greater or less numbers, the various individuals which together make up the whole species. And this district is called the "range," "habitat," or "specific area" of the lion *(Felis leo)*.

The existing "specific area" of the lion *(Felis leo)* comprehends Africa and South-western Asia up to Central India. I say *existing*, because we know that the areas of many animals have been materially altered, even during the historic period. Thus, the lion occurred in South-eastern Europe in the days of the Persian invasion, and in preceding geological epochs was abundant all over the continent, and even in England itself.

But although the lion and all other animals, especially the larger forms, which are least easily reconciled with man's presence, are continually altering their ranges or specific areas, this alteration is a slow, in many instances secular, process; so that for all practical purposes the "range" or "specific area" of an animal may be considered, like the rest of its specific characters, to be constant.

Let us now take other species of the larger and better-known cats:—

The tiger (*F. tigris*): Southern and Central Asia.
The wild-cat (*F. catus*): Northern and Central Europe.
The cheetah (*F. jubata*): Africa and S.W. Asia.
The serval (*Felis serval*): Africa.
The puma (*F concolor*): Central and South America.
The jaguar (*F. onca*) Central and South America.
The pampas cat (*F. passerum*): pampas of South America.

Each species, it will be observed, has a distinct and definite

"range," "habitat," or "specific area," and a naturalist would no more believe in a lion being found in America or a puma in Africa than in monkeys existing in the middle of the ocean or fishes on dry land.

Some of the species, you will remark, have a large range, some a small range, and such is the case throughout the animal kingdom. Some species are so widely distributed as to be almost cosmopolitan. But this is not often the case among mammals, except in the cases of such semi-domestic animals as the common rat and house-mouse; whereas among birds there are several instances, such as the osprey, peregrine-falcon, and sanderling, of almost universal distribution. On the other hand, many mammals are very local in their distribution, and confined to an extremely limited portion of the earth's surface. For example, the greater number of the species of lemurs are found only in certain parts in the Island of Madagascar: the moufflon sheep is met with only in Corsica and Sardinia; and the duckbill or ornithorhynchus is confined to the fresh waters of the colony of New South Wales. Amongst birds we have instances of still more restricted specific areas as in the case of the Pichincha and Chimborazo humming-birds, which are only found on the two mountains after which they are respectively named.

But to return to the various kinds of cats of which I was just now speaking. These, and the other known species of cats, make up altogether the genus *Felis* or cat, *genus* being the technical term used to denote an assemblage of nearly-allied species which have certain common structural characters. The genus *Felis*, then, comprehends all the different known kinds of cats, and is distinguished from all other genera of Carnivorous Mammals by a peculiar structure (arrangement of teeth, limbs, and internal organs), which structure is alike in all species of *Felis* or cat, but is not found in other Mammals. Now, just as we found in the case of each species of *Felis*, so in like manner the genus *Felis*, as a whole, has a certain definite range over the earth's surface, which is called its "generic area." This area is made up of the sum of the specific areas of the various species which make up the genus, and within it alone the various species are met with. These "generic areas," like "specific ones," may be large or small. In the particular case of *Felis* or the cat-genus, the area is large, embracing nearly the whole world, except Australia and Madagascar. But in other cases, as we shall presently see, it is small. For example, the true kangaroos (genus *Macropus*) are confined to Australia; the tree-kangaroos (*Dendrolagus*) to New Guinea; the lemurs

(Lemur) to Madagascar; the marmosets *(Hapale)* and the squirrel-monkeys *(Saimaris)* to certain portions of tropical America.

Proceeding a step higher in the usual plan of classification, we find nearly-allied genera united together into larger groups called "families." Thus, the cat family (or *Felidæ* of scientific naturalists) comprehends the genus *Felis* and other genera allied to it; the dog family *(Canidæ)*, the genus *Canis*, or dog, and other dog-like animals; the bear family *(Ursidæ)*, the genus *Ursus*, or bear, and other genera allied thereto. Just as is the case with genera or groups of species, each family or group of genera occupies a certain definite geographical area on the world's surface, which may be called the family area, and is made up of the area of the genera which compose the family.

It should not be forgotten to mention that the areas of the different species of the same genus frequently overlap one another, as also the generic areas of the same family. Likewise that when, in certain cases, the species is of itself the only one of its genus, the specific and generic areas are of course identical; and that, even in some cases where the form is of such peculiarity as to constitute a family of itself, the specific, generic, and family areas may be all the same.

When we come to divisions higher than families, the same rule of localisation, or restriction to a definite area, prevails. But in the case of the higher groups the area occupied is usually larger, and in some cases cosmopolitan. Thus, the order of bats, or *Chiroptera*, may be termed cosmopolitan, since bats are found in every part of the world except the polar regions. But of the two great divisions of this order, the insectivorous bats only are cosmopolitan, the frugivorous bats being entirely absent in the New World.

Again, the carnivora are universally distributed, except in Australia: the insectivora range over the whole world, except Australia and South America; the marsupialia, on the contrary, are only to be met with in Australia and in the New World.

It is not necessary to pursue this particular branch of the subject further, but we may sum up the results arrived at in the following propositions:—

Every species occupies a definite area on the world's surface; and in like manner every genus and family, or other higher assemblage of species, occupies a definite area on the earth's surface; or, more shortly, locality or existence in a certain spot is quite as much an attribute of animals as structure or the possession of a certain form or shape.

We must now proceed to consider a further point in the distribution of animals, which is, however, to a certain extent involved in what has gone before, that is, that the areas occupied by natural groups of animals, whether these are species genera or families, are or formerly have been continuous. By the term "continuous" we mean that they do not contain two different parts of the earth's surface without extending over the intermediate space. This statement, however, must be taken with a certain degree of restriction. Animals are in many cases attached to certain descriptions of country. Some are entirely arboreal in their habits, others aquatic; some are only found in open prairies, others in sandy deserts. The sloth, for example, passes his whole life in trees in dense forests—we do not expect to find him in the intermediate open pampas. Larks and chats are desert-haunting forms, which will certainly not be found in the intervening woods.

The "continuity" of an animal's area must not therefore be considered to be interrupted by its non-occurrence in a district not suited to its habits. As a general rule, however, it may be undoubtedly stated that a specific generic or family area is continuous, or that if such be not the case we can show (or *ought* to be able to show) some good reason why it is not continuous. There are certainly exceptional cases, in which a gap of greater or less size is found. But it is the very unfrequency of these exceptions, and the trouble taken by naturalists to investigate them and to discover some explanation of how they have come to pass, that proves the stringency of the general rule.

When we come to genera and higher divisions, the exceptions to the present continuity of these natural groups are much more striking and obvious. For example, it may be said monkeys are found in the tropics of Asia, Africa, and America. They constitute, without doubt, a natural group; but how can it be said that their area is continuous? To this it must be answered that the area of the order Quadrumana is certainly *not* continuous in the present condition of the earth's surface. But if certain theories of naturalists (which I shall more particularise by-and-bye), are correct, we must hold that monkeys and all other natural groups originated in one area, although subsequent alterations of land and water may have taken place and broken up this area. When geologists have put together the fragments they are now engaged in collecting of the former history of our globe, they will, no doubt, come to a solution of this and many other at present almost inexplicable phenomena. For the present, we must be content

to take a little on trust, and to assume, as a general rule, that—*Specific generic and other areas occupied by natural groups are, or have been originally, continuous.*

Having now considered some of the principal facts and laws of distribution in general, we come to the part of this great and important subject immediately before us, namely, the geographical distribution of mammals.

Mammals constitute the first and highest class of vertebrated animals. They are of special interest to us, as, whatever views we may hold as to the moral and spiritual nature of man and as to his origin, there can be no doubt that, considered as regards his bodily structure, he must be classified simply as a mammal, not very far removed in all essential points from some of the higher monkeys.

Mammals are divided by naturalists into about fourteen large groups, called "orders." As regards their distribution, however, these orders fall into two very different categories, according as they live on land or in the water—terrestrial and marine. For out of the fourteen orders, one of the principal divisions of the Carnivora—the Pinnipeds or seals, and two other orders in their entirety—the Cetacea or whales, and the Sirenia or herbivorous whales, are specially adapted for existence in water. Land is, therefore, a barrier to their extension, whereas, on the contrary, in the case of the ordinary terrestrial mammals, land is the means by which they extend their range, and ocean and rivers form their restraining boundaries.

We will for the present put aside the marine mammals, and address ourselves to the discussion of the distribution of the twelve terrestrial groups, namely:

1. Quadrumana.	7. Proboscidea.
2. Lemures.	8. Hyraces.
3. Chiroptera.	9. Ungulata.
4. Insectivora.	10. Edentata.
5. Carnivora.	11. Marsupialia.
6. Rodentia.	12. Monotremata.

But before we enter upon this, a few words may properly be said as to the general area of the earth's surface occupied to a greater or lesser extent by mammals generally. On the great continents of the old and new worlds mammals are everywhere to be met with, except on the tops of the highest mountains. We have not yet penetrated quite to the North Pole, so it is impossible to say whether that may prove to be an exception. But there is no reason

to suppose this, because at the highest northern latitudes to which man has yet penetrated, mammal-life has been found to be abundant. In the extreme north of Smith's Sound, in northern Greenland, in latitude 81° 38′, where the "Polaris" wintered in 1871-2, Captain Hall tells us that in the month of June "the plain was free from snow, and a creeping herbage covered the ground, on which numerous herds of musk-oxen found pasture, and rabbits and lemmings abounded." In the newly-discovered Franz-Joseph's Land, also, bears were found; and whales and seals occur abundantly in the highest latitudes yet visited.

In the case of the South Pole circumstances are very different, the complete isolation of the south-polar land having prevented the introduction of mammals, although birds and other forms of life are by no means absent.

The more remote oceanic islands in the Pacific and elsewhere are likewise mainly devoid of mammal-life, except such as is of a domestic nature, and the rats and mice which follow wherever civilised life penetrates. New Zealand also may be almost placed in this category, being, as regards mammals, only tenanted by two small species of insectivorous bats. There is indeed a vague tradition of a "native rat," but I have never heard of an actual specimen having been obtained. Our newly-acquired colony—the Fiji Islands—is, I believe, still worse off, only a single bat being known to occur there; and such is the case with most other islands removed from continents. But mammal-life extends throughout the chain of the West India Islands, and those of the East India Archipelago which connect Asia with Australia. Madagascar is also, as I shall presently point out to you, the seat of numerous and very peculiar forms of mammals.

Generally, therefore, it may be stated that terrestrial mammals are found all over the land-area of our earth, with the exception of the smaller oceanic islands far removed from any continent, and from the lowest plains and seabord up to the perpetual snow-limit of the highest mountains.

We will now proceed to consider *after what manner* terrestrial mammals are distributed over the above-mentioned area, and what are the principal laws which seem to regulate this distribution.

Before we do this, however, I must call your attention to the fact that, general laws being only to be gathered from particulars, an exact knowledge of the range or area of every mammal should be obtained before we attempt to settle positively the general laws of distribution. Now this exact knowledge we are at present far

from possessing. In the first place knowledge of geographical distribution must be preceded by a perfect knowledge of classification. We must know what an animal really *is*, and what are its differences from allied forms, before its locality and range can become of any real value. To take the case of any island or other district of which it is required to ascertain the general character of the animal and vegetable life, every plant and every animal should be collected, examined, and determined before this problem can be satisfactorily answered, and even a few errors may be of serious importance. Now our knowledge of classification is at present very imperfect, even in the case of mammals, which have been more closely studied, and are, perhaps, better known to us than any other class of animals. It follows that our knowledge of their distribution is also by no means complete; in fact, the subject is nearly a new one, and, I may almost say, that it is only amongst the most advanced and enlightened students of nature that its true importance is even now appreciated. "Locality," which, as I have just pointed-out, is quite as much an attribute of organised being as structure, has, until these last few years, been comparatively overlooked. Even in the best arranged public museums it is not uncommon to see gross errors in the localities affixed to specimens, or such vague indications as serve to give nothing but the most general idea of where the animal is to be found in its native state. And the same is the case, I regret to say, in many of the most common text-books of Natural History—*e.g.*, "East Indies," "West Indies," "South Sea Islands," and such like, are localities often employed, which are utterly valueless for scientific purposes.

I repeat, therefore, that to trace out the general laws of distribution, we must have an exact knowledge of its particular facts. To discover the general laws of the distribution of mammals, we must first know the distribution of every species of mammal exactly. Not only do we not yet know this, but we are not yet acquainted with all the species of mammals, even in the case of the most conspicuous and most important groups. Within these last few years most important additions have been made to the list of known mammals, such as new tapir and a new rhinoceros, new deer, and new forms among the larger carnivora and quadrumana. *Tapirus bairdi* of Central America, *Rhinoceros lasiotis* of Chittagong, *Cervus alfredi* of the Philippine Islands, *Æluropus melanoleucus* of Chinese Thibet, and *Rhinopithecus roxellana* of the same district, are examples of such discoveries.

Again, errors in distribution and wrong deductions are often

caused by false classification. If an animal really belonging to one natural family is wrongly referred to another, a serious error in the range assigned to each group is likely to follow. For example, it was until lately supposed that, as regards the *Viverridæ* or civet-family of the carnivora, there was a singular anomaly in the fact that they were all confined to the Old World except a single genus *(Bassaris)* which occurs in Mexico. But Professor Flower has recently shown that *Bassaris* belongs really to the *Procyonidæ* or racoon family of the New World; so that this apparent anomaly has no real existence.

Again, the musk-deer *(Moschidæ)* have been supposed until lately to be distributed over India and Africa. But it has now been shown by Alphonse Milne-Edwards that the supposed Indian and African members of the group constitute a very different family of the Ungulata—the Chevrotains or Tragulidæ. The musk-deer, therefore, now consists only of a single form *(Moschus)*, of Central Asia. This is another instance of how much our knowledge of distribution depends on classification.

I have said thus much by way of caution before entering upon the next branch of my subject, which is—taking the facts as regards the distribution of terrestrial mammals, so far as they are known to us, as our guide—how the world may be best divided into zoological regions.

This problem is, of course, only a subordinate part of a much larger one, namely, how the earth may be most naturally divided to correspond with the distribution of the whole of organic life—that is, all the animals and plants known to exist on it. To solve this larger problem, the range and distribution of every group of terrestrial animals and plants must be separately discussed and carefully investigated. That is, we should require to know the exact distribution of each of such groups, as—

1. Mammals.
2. Birds.
3. Reptiles.
4. Batrachians.
5. Fresh-water Fishes.
6. Land-shells.
7. Insects.
8. Fresh-water Crustaceans.
9. Plants, &c.

Now, if there is still so much wanting to be known, even in the much-studied class of mammals, before we can attain a complete knowledge of their distribution, you may judge what an enormous number of facts have still to be ascertained before the whole subject of the general distribution of animal and vegetable life can be completely investigated.

At the same time, we must recollect that nature is, above all things, harmonious. Her laws cannot be discordant, though our interpretation of them may seem to indicate a want of harmony. If, therefore, we can correctly interpret the known facts of the geographical distribution of mammals, and deduce certain laws from them, we may be sure that these deductions will be ultimately reconciliable with what is discovered upon the examination of other classes of animals and plants—due allowance being made for the various peculiarities of each class.

So much being premised on both sides of the question, we will now proceed to discuss the problem—

Given the facts of the distribution of terrestrial mammals so far as they are known to us, how to divide the land surface of the globe into its most natural divisions.

The ordinary geographer's division of Europe, Asia, Africa, America, and Australia may be easily shown to be incorrect, and will not answer for naturalists. In the first place, Europe is but a mere fragment of Northern Asia, and belongs to the same division zoologically. Again, Africa north of the Atlas is peopled by the same forms as inhabit the northern shores of the Mediterranean; whereas the animals of the great mass of that continent are wholly distinct. Moreover, as can be easily shown, a considerable part of the land north of the isthmus of Panama belongs zoologically to South America.

Let us, therefore, cast geographers' notions aside for a minute, and begin at the other end. The twelve orders of terrestrial mammals are, according to the best authorities, arrangeable under three very distinct heads—

I. Monotremes, or Ornithodelphs.
II. Marsupials, or Didelphs.
III. Typical mammals, or Monodelphs.

Now, when we come to examine the distribution of these three groups on the map, we shall find that the Monotremes are wholly confined to Australia; that the Marsupials predominate in Australia, and are only met with elsewhere in South America (one or two species of opossum *(Didelphys)* occur in North America, but are probably only recent intruders from the south); and that the main part of the typical mammals is distributed over the rest of the world.

Again, after examining the distribution of the ten orders of typical mammals, we remark the following significant facts:—

1. The absence of insectivora in South America.

2. The prevalence of Edentata in the same country; the sloths, armadilloes, and ant-eaters, three out of the five known families of this Order, being entirely confined to South and Central America.

Taking these main facts, we may divide our earth, as follows, into four divisions :—

I. Land where monodelphs only occur; no marsupials nor monotremes	Europe, Asia, Africa, Asiatic Islands down to Wallace's Line, and North America down to the Isthmus of Tehuantepec.

Arctogæa—North-land.

II. Land where monodelphs and marsupials occur; no monotremes	America, south of the Isthmus of Tehuantepec.

Dendrogæa—Tree-land.

III. Land where marsupials prevail; no other monodelphs but rodents and bats; monotremes	Australia.

Antarctogæa—South-land.

IV. Land without mammals (except bats).	New Zealand and Pacific Islands.

Ornithogæa—Bird-land.

The fault of this division is that it leaves the great mass of land in the northern hemisphere undivided and rather unmanageable. But this Arctogœa or northern land is easily separable into four sections, although it must be understood that these sections are not really equivalent in value to the two remaining undivided primary divisions. Thus leaving out the fourth primary division, where no mammals are found, we obtain a division of the land-area of the globe for mammals into six areas, which may be called REGIONS, and defined and named as follows :—

ARCTOGŒA.	I. Europe: Africa north of Atlas: and Northern Asia.	*I. Palæarctic Region.*
	II. Africa, south of Atlas, and Madagascar.	*II. Ethiopian Region.*
	III. S. Asia, Philippines and Islands of Indian Archipelago down to Wallace's line.	*III. Indian Region.*
	IV. N. America, down to Isthmus of Tehuantepec.	*IV. Nearctic Region.*

DENDROGŒA.	V. Central America, south of the Isthmus of Tehuantepec, and South America.	*V. Neotropical Region.*
ANTARCTOGŒA.	VI. Australia, N. Guinea, and islands up to Wallace's line.	*VI. Australian Region.*

We will now take a brief survey of the principal features of these six regions—as shown in the accompanying chart—and their most characteristic mammal-forms.

1.—Palæarctic Region.

Name.—παλαιὸς ancient, and ἄρκτος north, as embracing the whole northern area of the old world.

Boundaries.—Land north of a line south of the Atlas, and running eastward through south of Palestine and Persia, along the Himalayas, through Central Asia and the centre of China to the Pacific.

Characteristics.—Absence of monkeys, lemurs, and frugivorous bats; abundance of *Carnivores*—ounce, lynx, wolves, foxes, bears, weasels, glutton; *Rodents*—marmots, beavers, pikas; no elephants nor hyrax: *Ungulates*—sheep, deer, chamois, and musk-deer.

2.—Ethiopian Region.

Name.—Αἰθίοπες, ancient name for negroes.

Boundaries.—Africa, south of the Atlas; probably Arabia up to Persian Gulf, and Madagascar.

Characteristics.—Chimpanzee and other monkeys: no bears; lion; African elephant; hyrax; rhinoceros; hippopotamus; wart-hog—numerous antelopes, but no deer; giraffe; manis; ant-bear—generally rich in large and highly-organised mammals.

2A.—Lemurian Sub-region.

Name.—Derived from *Lemur*, the prevalent type.

Boundaries.—Madagascar and Mascarene Islands.

Characteristics.—Home of the lemurs, few being found elsewhere; absence of cats and ruminants; tenrecs.

3.—Indian Region.

Boundaries.—Southern Asia, south of the Palæarctic Region, and Islands of Indian Archipelago, down to Wallace's line.

Characteristics.—Orang and other peculiar monkeys; flying-lemur; tiger, leopard, and other cats; Indian elephant; rhinoceros; Malayan tapir; manis.

Generally it may be said that peculiar groups are fewer than in the Ethiopian region, and that the Indian has bear, deer, and tapir, which are wanting in the latter.

4.—Nearctic Region.

Name.—νεὸς new and ἄρκτος, *i.e.*, northern district of New World.

Boundaries.—America, down to Isthmus of Tehuantepec.

Characteristics.—General mammal-fauna very like that of the Palæarctic region, and probably of recent origin from the west. Bears, beavers, sheep, and deer similar; prong-buck, pouched mice and musquash peculiar; racoon and opossum, probably derived from the south.

5.—Neotropical Region.

Name.—νεὸς new and τρόπικος, *i.e.*, southern land of the New World.

Boundaries.—America, south of Isthmus of Tehuantepec.

Characteristics.—Monkeys of the family Cebidæ and Hapalidæ; absence of frugivorous bats, and presence of vampires; abundance of porcupine family; absence of insectivores and civets; also of elephants; tapirs; no ruminants except deer and lamas; sloths, ant-eaters, and armadilloes; opossums.

5a.—Antillean Sub-Region.

Mammals few but several peculiar: *Solenodon*, *Capromys*, and *Plagiodontia*.

6.—Australian Region.

Boundaries.—Australia, New Guinea, and Moluccas, up to Wallace's line.

Characteristics.—Absence of monodelphic mammals, except a few rodents and bats; presence of six distinct families of Marsupials with 100 species, and the only two known Monotremes.

I have now put before you (or endeavoured to do so), a few of the principal known facts relating to the geographical distribution of terrestrial mammals. I have also shown you how the present land surface of the globe may be approximately divided into

zoological regions, so far as regards its mammals. We now come to the question, *What* is the meaning of all this? *Why* are animals distributed in the way in which we find them to be? *Why* has each country its particular set of animals, and *why* are species and other natural aggregations of animals confined to particular areas? To these important questions two very different answers have been given. The one view—that of Agassiz and his school, though not even by them carried out, I believe, to its utmost extremity—maintains that species are invariable; they were created, or came into being, in and over the area in which we now find them existing. The other—that of Darwin and his followers—maintains that species are ever slowly varying, that they are related by natural descent to each other, and that the present animal population of the earth is simply the modified offspring of what has been there ever since the beginning of time.

Now as regards the phenomena of distribution—if they are to be allowed any weight in the matter—there can be no question, I think, on which side of the balance they must be placed. Under the former hypothesis it may still be an interesting question to work out the area of every species, and the range of every natural group, but no sort of answer is given to the intelligent inquirer who demands why are these things so? We must simply reply because they *are*, and have been made so, and there is nothing more to be said on the subject.

On the other hand, if we adopt the Darwinian hypothesis of the derivative origin of species as a working principle, we shall find it a key which will unlock nearly all the most perplexing phenomena of distribution. For example, it explains why the individuals of each species are confined to a certain definite locality. They are simply the remote descendants of pre-existing species which occupied the same or a nearly contiguous area. Why do we so often find cases of "representative species," as they are termed, or of a series of different species taking each others places in adjoining areas, and evidently fulfilling corresponding functions in the system of nature? They are simply children of the same parents who have migrated from a common centre. Why are the animals of two distant parts of the world almost entirely different? Because of the length of time which it has taken their ancestors to travel from the common point of origin. Why are the animals of two near countries almost always identical? Because they have not yet had time to acquire differences. The philosophic view of *species*, and that which is now adopted by all our leading and most thinking naturalists, is, that

so far from being fixed in their characters, they are *ever slowly changing*. If we take any particular animal that has a wide range, we shall find that specimens obtained from the extreme parts of its area are almost always sufficiently different to be recognised on comparison. We know that Great Britain has not long been separated from the rest of Europe—that is, not long geographically speaking—and yet we find that many of our common birds have acquired certain peculiarities, even to such an extent as to cause them to be regarded by some naturalists as belonging to different species.

Now let us suppose an island occupied by a species of animal and in which individuals from the two extremities of the island already present appreciable differences. The island becomes divided by a broad channel into two islands. The two forms can no longer interbreed, and thus delay the rate of variation. On the contrary, the variation is intensified by those possessing the same peculiarities breeding *inter se*, and two "*representative species*" quickly result. There are numberless cases in the West India Islands, the Moluccas, the Pacific Islands, and all over the world, in fact, in which specific differences may have arisen in this way.

But the same result may take place, and does continually take place, on continents, without the intervention of aquatic disturbances. The area in the middle of the range of a species becomes deserted from some cause, and the result is the growth of an allied representative species in each of the two divided areas. There can be no doubt that the origin of numerous species has taken place somewhat after this fashion. In short, by the aid of the theory of the gradual variation of species, we can explain *most* of the phenomena of distribution; taking the opposite view—that of the fixity of species—we can explain *none* of them.

Let us now, therefore, assume the derivative origin of species: let us take for granted that the greater or less resemblances of animals are simply a manifestation of their farther or nearer relationship by descent. Now, let us again look at the leading features of the general distribution of terrestrial mammal-life over the earth, which I have already set before you, and see whether we can make out at all how they have come about.

Australia (or *Antarctogæa*) is the most unlike all other countries in its mammal life; it has therefore been isolated the longest period. The probability is, indeed, that the few non-marsupial forms met with in it (bats, rodents, and the native dog) are all comparatively of recent introduction, and that its original mammal-

life consisted entirely of marsupials and monotremes. In the earlier part of what is called the secondary epoch of geologists, the only existing form of mammal-life was marsupial, and marsupials then existed in this country, and probably all over the land area of the earth. In those days Australia was joined to the then Arctic continent: since then it has remained separate, and has for some reasons, at present unknown to us, retained its marsupial features of mammal-life, which have perished or become superseded by higher forms in the rest of the world.

Again, we see that after Australia the Neotropical Region *(Dendrogæa)* presents the most strongly marked features of individuality as regards its mammals. Observe its strange forms of edentates, and its peculiar group of marsupials. There can be no doubt, therefore, that the Neotropical Region, or the greater part of it, was until recently, and for a long period, separated from the northern portion of the New World, to which it is now joined, and that it contains land that was formerly part of the great "*terra marsupialium*," since we find marsupials still lingering there.

More recently it has been united to North America, and has received a certain number of immigrants from the north, such as *Ursus*, *Mustela* and *Lutra*, and has parted with one or two opossums, which have intruded themselves into the Nearctic Region.

The higher or Monodelphic type of mammal life must have originated in a great tertiary continent, situate somewhere in the northern hemisphere, whence it has diffused itself into every part of Arctogæa, perhaps exterminating the marsupials, which prevailed there before it. Of the constituent regions of Arctogæa, as I have arranged them, the Ethiopian and its Lemurian neighbour appear to have been first separated off, since they possess most individuality. The Nearctic region possesses a few peculiar types (such as *Antilocapra*, *Condylura*, and the Saccomyidæ, and was probably separated and again rejoined, when it was overrun by Palæarctic forms.

But I must cease my speculations, which can be deemed little more than conjectures, until we know much more than has been yet ascertained of the geological structure of the globe, as well as of the animals that now inhabit it and have inhabited it in former ages. I trust, however, that the facts I have put before you, and the deductions I have endeavoured to draw from them, may have induced some of you to take more interest in that somewhat neglected branch of Biology—the geographical distribution of plants and animals.

Earthquakes and Volcanoes.

A LECTURE, delivered in the Hulme Town Hall, Manchester, on Wednesday, December 2nd, 1874.

By Professor W. C. WILLIAMSON, F.R.S.

MR. Chairman, Ladies, and Gentlemen,—In selecting, as the topics of my lecture, Earthquakes and Volcanoes, I want, if I possibly can, to make the subject popular and plain to you, but not to rob it of its scientific character. In this country we happily are not very much disturbed by earthquakes and volcanoes; and, as I came down here to-night, I could not help reflecting upon what would be the social condition of England if earthquakes and volcanoes prevailed here as they do elsewhere. If you can realise what would be the consequence of one earthquake wave rolling freely under Manchester for ten seconds, and fancy to yourselves the toppling down of tall chimneys and the rattle of bricks and mortar that there would be on every side of us, you may form some little conception of how impossible it would have been for Manchester ever to have become what it is, if such evils as that to which I have referred had from time to time afflicted us. But, by a happy dispensation of Providence in the arrangements of nature, England has been spared this great calamity. But, though it would be a calamity were it to come here, I hope to be able to show you, before the lecture of to-night is completed, that so far from earthquakes and volcanoes in general being ranked amongst the calamities of the world, they are some of the necessary agents of nature without which the world would have been of much less use to mankind than it is.

The first thing to which I would call your attention is the range of the geographical lines along which volcanic phenomena most frequently exhibit themselves. For this purpose I would direc your attention to an outline map of the world. [A large

map of the world and coloured illustrations of volcanic regions, &c., were suspended on the wall.] The parts of the map which are coloured continuously are the parts of the world that are more or less seriously affected by earthquakes. There are certain spots which I have coloured dark red; those spots indicate the position of volcanoes that are in action. There is another class of localities where volcanoes have been active in by-gone times, but where volcanic action has ceased to exhibit itself. Thus you see we are able to classify these localities into extinct volcanoes, active volcanoes, and regions affected by earthquakes. The subject of extinct volcanoes, however, I must leave entirely out of our consideration to-night. Now the first thing you will notice here is a long line of volcanic action, interrupted at intervals, running along the western coast of the American continent. Then, if you go round to the other side of the map you find that you have again a chain of these volcanic regions, beginning at the Aleutian Islands, running down the Chinese coast, and abundantly expanded in the Malay Archipelago. Then you see beyond this another disturbed region, commencing near Lake Baikal in Central Asia, running across by the Caspian and Black Seas, and especially continuing along the northern shores of the Mediterranean. The first thing that will strike us on referring to this map will be the circumstance that we rarely find active volcanoes far away from the sea. They are generally located near the sea-coast; or if not near the sea-coast, near great bodies of inland water. The main exception to this rule is found in the district to the north of India; but even there the volcanic region begins at one of the largest of the Asiatic lakes, and it comes in contact with the Caspian Sea, the Black Sea, and the Mediterranean. So that notwithstanding the apparent exception, we still find that there are large bodies of water within comparatively easy reach of these disturbed areas.

When volcanic phenomena are about to manifest themselves, especially when earthquakes are going to disturb the earth, the disturbed region generally indicates the approaching action through meteorological or atmospheric phenomena. I will tell you what this means. There are districts where rain is either unusual or is only experienced at certain seasons. When earthquakes are about to shake such regions we often have violent rain. Then periods of storm will be followed by periods of most unnatural calm. Sometimes there will be heard underground rumblings like thunder, or like a railway train running along subterranean tunnels. Not

only so, but even the very animals of the field appear conscious that something is impending, and they frequently give utterance to their fears by cries and by exhibiting restlessness and alarm. Even man himself not unfrequently feels that kind of uncomfortable sensation to which our French neighbours give the name of *malaise*. Various other phenomena of a similar kind are witnessed, showing that the atmosphere is in sympathy with the earth, as is undoubtedly the case with explosions in coal mines, with which we are but too familiar; but whether the volcanic disturbances in some degree depend upon these atmospheric conditions, or cause them, I will not venture to say, but I think that the former is not altogether improbable. Be that as it may, there is some mysterious sympathy between the subterranean movements and the conditions of the atmosphere overhead.

It would, perhaps, surprise you if I were to put before you to night a list of the more remarkable earthquakes that have disturbed the world within the last one hundred years. Sir Charles Lyell, that veteran labourer in the field of geology, published in his great work on the principles of that science, a list of the leading earthquakes that had occurred up to the year 1837. From 1750 up to 1837, there had occurred no less than nineteen most violent and destructive earthquakes. If such a number of violent earthquakes—leaving out of sight thousands of minor ones—convulsing the earth, in many cases, for hundreds of miles around, have taken place in little more than sixty years, one may form some conception how many shocks old mother earth must have had from the beginning of her existence. Instead of attempting to give you any very technical exposition of the scientific part of this subject, I think I cannot do better than select three or four of the leading earthquakes that have taken place—point out to you what occurred on each of those occasions—and in this way teach you—not by experiment, as our Chairman does when he flashes his magnificent lights amongst us—but showing by nature's experiments, what the phenomena of volcanic disturbances really are.

One of the most interesting, though not one of the most violent, earthquakes we ever had, was one that occurred at Chili, on the western coast of South America, in 1822. It fortunately happened that there was residing in the disturbed district an English lady of more than average intelligence, even for English ladies. Mrs. Graham took very careful note of all the phenomena that occurred at that earthquake; and though on previous occasions various observers had recorded similar

phenomena, it was found that the data which Mrs. Graham gave to the world were more valuable, especially to geologists, than any that had been given before, because they were exact. The earthquake in question affected about 1,200 miles of sea-coast from north to south; it was felt some hundreds of miles out at sea, ships being affected by the shock. But the most significant fact that was brought to light (and here lay the great value of her observations) was the discovery, that after the earthquake had ceased its action the levels of land and sea along that coast were permanently changed. She found that at places where ships of a considerable burden could formerly float, they could float no longer; that rocks in the harbours that were previously covered by the tide when the tide was up, were covered no longer; that, in a word, the whole coast-line for hundreds of miles had been more or less elevated by the shock. In the more central places this permanent elevation above their original level amounted to some three or four feet. It thus became established as an indisputable fact that one of the permanent effects of violent earthquakes was the production of a definite change in the relative levels of land and sea; and inasmuch as geologists had a very large number of such results to explain, they here at once obtained a clue based upon unquestionable fact as to the probable agents by which these elevations had been accomplished. That such was the probable explanation of these elevations was known before, but here probability became converted into certainty; and we were shown that there was in nature a definite power still working in our midst that was able, by a succession of small blows, acting through thousands and millions of years, to produce the most extensive phenomena that the geologist had brought to light.

At a somewhat earlier period another very remarkable earthquake took place on the opposite side of the globe. There is a very curious district at the mouth of the Indus belonging to the territory known by the name of Cutch. The large area, called the Runn of Cutch, was affected by an earthquake in 1819. On that occasion the area disturbed was so large that it had a radius of something like a thousand miles. But here the effects produced were the very opposite of those produced by the South American earthquake. In the former instance a large territory, some 2,000 square miles in extent, that had previously been either dry or, at all events, only swampy land, sank bodily beneath the surface of the water, and now exists as a gigantic inland sea. Forts that before stood upon dry land are now submerged. The Fort

of Sindree is below the water so far as its lower works are concerned, but the upper stories are still above the water, showing the place where this fortified station once stood. But it is a very remarkable fact, that whilst so large a portion of the great Delta of the Indus was thus being permanently lowered, there was a considerable area, some fifty miles to the north of the district, that was permanently raised. So that here we had a double action going on—one part of the earth was depressed and another part was lifted up, as if there had been some pressure upon two distant points tending to subject the earth to a lateral squeeze between these points. Since the land did not yield, as paste or putty would yield, it assumed the undulating outline that must inevitably be given to a plane that tried to sink into a smaller area than it occupied previously, and where there was not space enough to receive it. We shall have to refer to this again by-and-by.

Another of these fearful earthquakes was that of Calabria, a well-known one that we used to read about in our school books when we were boys. This earthquake occurred in 1782. On that occasion the disturbances were most fearful, because they continued to recur at intervals through a period of something like four years. The destruction of life on the occasion of the Calabrian earthquake by the falling of buildings was frightful. It is supposed that not less than 40,000 people perished thus; and as such a destructive event entailed famine and misery afterwards, some 20,000 more fell as victims of the epidemics that almost depopulated the Calabrian territory. On this occasion that very remarkable phenomena which is known as the sea-wave did its work. When an earthquake takes place in the neighbourhood of the sea-coast it generally happens that at the time of the shock the sea retires, leaving its bed dry, or at all events leaves it uncovered with water. But this retreat of the ocean is followed in a few moments not only by its return to its former level, but in its retreat and return it has gained a fearful impetus, so that in almost every instance it rolls in upon the land, adding to other miseries that of drowning, thousands thus perishing in addition to those destroyed by the direct action of the earthquake. We shall have to see if any cause has been found for this remarkable sea-wave.

On the first of November, 1755, a still more frightful earthquake occurred, as many of you are doubtless aware. The city of Lisbon was the victim of this terrible calamity. On that occasion there seem to have been concentrated upon that ill-fated city all the

combined evils that ever afflicted a volcanic region. That beautiful city, nestled upon the shore of its noble river in the utmost calmness and beauty, when, in a few moments, it was changed into one mass of ruin. 60,000 persons perished, chiefly by the fall of buildings, but also by a remarkable occurrence which took place, and which is without a parallel in the history of volcanic disturbances. Alarmed by the shock multitudes of the people retreated with all possible speed to the banks of the river, where there was constructed a large marble quay. All at once this stupendous structure yielded under their feet, and in a few moments it sunk under the water, going down into the depths with every soul that was upon it; the entire structure and every individual became so engulphed in some awful chasm, that not the slightest trace of that seething mass of people ever came to the surface—they went down into the abyss, and there they remain entombed to the present moment.

On this occasion the area of the disturbance within which the shock was actually felt was more than four times that of Europe. The outline which you see here represents the disturbed district. The actual shock was felt within this inner oval, which embraces the southern parts of Norway and Sweden and the British Islands, and it caused fearful destruction in the northern parts of Africa. But this was not all. Secondary effects of the shock were felt in Newfoundland and the northern parts of the United States; it also affected many of the West Indian Islands, where some of these effects were very remarkable. You are probably aware that in most of the West Indian seas you have scarcely any tides. But on this occasion the tides, that were usually not more than two feet high, rose suddenly to a height of twenty feet, inflicting serious calamities upon the people and their dwellings. Not only so, but in other parts of the West Indies this force, whatever it was, stirred up the bottom of the sea, and the waters became black as ink; showing that at a distance of hundreds of miles from the centre of the disturbance the force was violent enough to disturb the lowest depths of the ocean.

I have probably said enough on the subject of earthquakes to show you how wide-spread is their action. But we see that though this action may be widely diffused, it has a centre upon which it expends its utmost power. It is upon that centre that the chief destruction takes place; at the more distant regions the phenomena are rarely of a destructive kind. This points us to some local agent acting immediately below the spot upon

which this force is chiefly expended. We shall have to say a word about that subject in a few minutes.

But now let us leave the earthquake, and turn to the yet more remarkable phenomenon of the volcano. I have already pointed out to you that along these lines of disturbance there are volcanic peaks, some of which are now in violent action from time to time, like Vesuvius and Etna, and similar burning mountains in other parts of the globe. There are other volcanic peaks, on the contrary, like those of Auvergne, in France, where you can still trace the lava streams that once flowed from the burning cones, in various directions, but where volcanic action is now entirely at rest. But do not let us suppose that because volcanic action is slumbering, that therefore it will never break out again. I shall have to show you a fearful instance to the contrary.

One of the most curious volcanic phenomenons on record is chiefly remarkable because it produced its fruit within a comparatively recent period. There was a very calm region bordering upon one of volcanic disturbance. I mean the Bay of Naples, at one end of which, as you know, stands Vesuvius. Near it is that district so well known in classical story as the Phlegræan Fields, in which, according to the old classic authors, was the cave of the Cumæan Sybil—the entrance into a warm territory that shall be nameless, and inhabited by those whose company neither you nor I want to keep.

In this particular locality a volcanic disturbance took place in 1533. There had previously existed on that spot the small town of Tripergola. After some previous shocks of earthquakes, the ground suddenly sank fourteen feet; but it as quickly rose again, like a blown-out bladder, until the tension of the earth was fairly overcome, and then it burst and again collapsed. The result of this collapse was the formation of a deep fissure and the appearance of flames issuing therefrom, while mud, ashes, and lava were thrown up into the air, and in twenty-four hours the place occupied by the town of Tripergola became the base of the mountain now known as the Monte Nuova. This mountain is now 440 feet in height; its circumference measuring about a mile and a half. Now, we have here a volcano of the simplest form, and of which we are able to trace the process of formation, for it happened that there resided on the spot some extremely intelligent Italians who watched the whole affair, and whose records are still in existence. These records prove that in this case there was first a force exercising a downward pres-

sure, which was followed by a reactionary pressure in the oppo site direction. A fissure then forms in the ground; that fissure opens the way, through mysterious depths, to the great laboratory where nature's work is being carried on, and through that crack she pours out her products in such marvellous quantities that in 24 hours she is able to construct a mountain that has remained to the present time. That mountain is now calm enough: it is covered with vegetation, and the Neapolitan shepherds feed their flocks upon its slopes.

A still more marvellous phenomenon took place in a district that is also classic, and with which every one of you is more or less familiar—I mean Mount Vesuvius. In the time of the Augustan age—that age, let me remind you, when One whom many of us, at all events, believe to have been Divine, lived upon earth—Vesuvius was apparently an extinct volcano; it was then perfectly quiescent; its huge cone existed as now, and its crater was probably larger than it is at present. It was covered with grass, and peasants led their flocks into the recesses of its crater. No one had the faintest suspicion that there existed underneath it any source of danger. But in the year 79 ominous movements began to take place; earthquakes became very frequent. At first slight, they rapidly became more violent, and soon afterwards the mountain burst forth with that extraordinary outbreak of volcanic power, of which a marvellously beautiful description has been left us in a letter to Tacitus, written by the pen of the younger Pliny, the nephew of the great Roman naturalist. Those who are familiar with Roman history know that the letters of the younger Pliny are classic works. One of those letters was written to the great Roman historian Tacitus, giving him an account of what took place at this great outbreak of the Vesuvian cone. It so happened that at the time of the eruption the elder Pliny was admiral of the Roman fleet, which then happened to be stationed at Misenium, the great naval port of the Bay of Naples. Finding that this outbreak was endangering the dense population dwelling on the slopes of the mountain, and especially around the shores of the bay, he moved the fleet across to the foot of the mountain, for the purpose of giving aid to those who were in peril, as well as of obtaining a nearer view of the eruption. He landed, stayed a short time at the house of a friend; but as the atmosphere became darkened, and stones began to fall from the sky in dangerous quantities, he and his companions sought to effect their retreat. They protected their heads with pillows, to guard them from the

falling cinders and burning ashes. Most of them made their escape; but, unfortunately, poor old Pliny had the calamity of being rather fat; the heat and the labour proved too much for him, and he fell suffocated by the vapours which filled the air. On this occasion the whole of the ancient cone was blown to pieces. Vesuvius, in all probability, still retains traces of that eruption.

I have drawn for you a view of Vesuvius as it now exists. A line of villas extends along the shores of the Mediterranean. Here is the valley between Monte Somma and the central peak, so well known as Atrio del Cavallo. It is the valley where travellers leave their horses, because they are unable to take them up to the peak; they can ride to that point, beyond which they must walk. On the opposite side of the mountain there is a slight shoulder, known by the name of the Pedimentina. There is every reason to believe that a line connecting these two points represents the crater that was left by the volcano after the eruption of 79. I have told you that the peak was nearly blown away; it either went up into the air and fell in the surrounding district in the shape of stones and ashes, or it sank into the depths and was re-melted. Be that as it may, it is a generally accepted fact that Monte Somma was the northern margin of the great crater of 79. But, as you perceive, at later periods fresh peaks were formed in the interior of the old crater, and one of these constitutes the summit of the mountain at the present day. If we were to make a section through the centre of that mountain, the probability is that we should find such a structure as you see in another diagram, showing the ancient crater, and the funnel or chimney through which communication is maintained between the crater and the interior of the earth. You will observe in this diagram that the lines representing the volcanic material composing the mountain appear to fall away from its apex on each side. It is evident that a volcano is a very complex structure. You have in certain places layers of ashes; in others these are separated by layers of lava. You will understand these layers of lava better if you glance at this ground-plan of the mountain, which I have copied from the work on Vesuvius published by my old friend, the late Professor Phillips. In it you will see numerous differently-coloured streams flowing from the central peak. The greater part of the grey colour represents ashes of an unknown age. Then you observe certain streams of lava represented by a brown colour; these are known to have flowed from the cone during the nineteenth century. You further observe other lavas, coloured blue, and which belong to the eighteenth

century. A third set of streams, coloured pink, belong to the seventeenth century. Try to realise for a moment that during these three centuries Vesuvius has been repeatedly throwing fragments of lava and ashes high into the air, and which have fallen down and formed a huge conical heap—that at the same time streams of lava have been flowing in more or less extensive streams in various directions; you will then readily understand that the result of these combined agencies would be the production of such a structure as we have represented here.

We must further bear in mind another phenomenon that takes place. Whenever one of these volcanic outbreaks occurs, there is very frequently some disturbance in the shape of earthquakes, which produce vertical cracks in the sides of the mountain. Those cracks go down into the earth to an unknown depth, whence the lava frequently enters them and fills them up. This is a fact of some consequence to us as geologists, because it enables us to explain certain perpendicular walls of volcanic rock that run through many countries for miles and miles. We have abundance of such in our own island. It is evident that these "dykes," as they are called, are precisely like these lava fissures, which you see in this diagram, representing a cliff on Mount Etna. Here you see the horizontal lines of the ashes intersected by perpendicular walls of solid crystalline lava. It is evident that the lava was forced upwards into these cracks, in a heated and fluid state, and that it afterwards cooled and became hardened into these vertical walls. Thus instructed, we have no difficulty in explaining these ancient dykes of various geologic ages, which are found in many parts of the country.

Another extraordinary phenomenon took place in connection with this ancient outburst from Vesuvius. Most schoolboys have read of Herculaneum and Pompeii. At the present moment excavations are being made in these buried cities, bringing to light striking evidences of the life and civilisation of the Roman age. This Bay of Naples had long been the Scarborough or Southport of the Roman people, but the same outbreak destroyed both Herculaneum and Pompeii. In the case of Pompeii no true lava stream seems to have reached the city; it was partly buried by ashes, but still more by that peculiar material called lava d'aqua—water lava. Now the history of this lava d'aqua is important to us, because that history is intimately mixed up with that of the origin of volcanic force. You see issuing from these volcanic cones at times of disturbance vast

columns of what looks like black smoke. Pliny's description informs us that in the great earthquake of 79 this column of smoke appeared exactly like one of the Italian pine trees, shooting up with a tall stem, and then spreading out horizontally, something like the Scotch fir, with a huge flat head. The Italian or stone pine of Italy, the pine that Turner was so fond of introducing into his pictures, bears out this comparison more forcibly than anything we have at home. But it was not, and never is, smoke in the ordinary sense of the word—it is a mixture of water and ashes. It is not the sooty material which we have in Manchester. The dominant elements in this volcanic smoke are vapour of water and volcanic ashes. It has been estimated that in some of these great Vesuvian eruptions there exists in that black canopy that overhangs the mountain, not less than 20,000 cubic yards of water at each given moment of time. This water ascends in the shape of steam and vapour, and, rising into the higher regions of the atmosphere, it soon becomes condensed, and then it tumbles down in the shape of torrents of rain. But what has been taking place in the interval? The country for miles around has been covered with thick layers of fine volcanic ash. Pliny found it to be so in his day, and the last eruptions have shown us repetitions of the same thing. The country thus covered with this impalpable volcanic ash is then deluged with tropical rains, until the ash is converted into a mass of flowing mud. It was torrents of this mud and showers of ashes that brought destruction upon Herculaneum and Pompeii. The fated cities stood on the lower slopes of the mountain, down the sides of which torrents of this lava-mud flowed into their streets and buried their luxurious mansions. Pompeii seems to have been chiefly buried beneath showers of dry ashes. The fine mud entered the smallest cavities, and thus formed perfect moulds of the numerous objects which are to be seen in the Neapolitan Museum. The director of the excavations had the genius to adopt a particular mode of recovering many of these relics. During these excavations he found that many of the objects that were enclosed had become mere dust; but it occurred to his mind to pour into the cavities which they had once occupied, plaster of Paris, and thus perfect casts were obtained corresponding to the objects which these moulds originally contained. One of the most touching illustrations of this tragic scene, brought to light by the excavations, was the perfect cast of a female with an infant in her arms. If we turn to Herculaneum we see something different

has occurred. Here, in addition to the mud and ashes, layers of lava have flowed over the town. It is a popular mistake, however, to suppose that Herculaneum was originally overwhelmed by streams of lava. It has been so overflowed again and again, but, like Pompeii, Herculaneum was first destroyed by ashes and lava d'aqua. At a later date streams of lava reached that fated city; but we have no reason for believing that any lava flowed over Herculaneum at an earlier period than the tenth century.

Let us now turn to a still more remarkable mountain—I mean Etna. Mount Etna is very much larger than Vesuvius; it is between 10,000 and 11,000 feet in height. I have attempted to give you in this drawing an idea of its general form. Here you have the fertile and vine-clad plains of Sicily, above which the mountain resolves itself into three regions. At its base you have an extremely fertile region covered with the rich verdure which characterises the sunny South. Beyond this you have a belt of forest, consisting of hardier trees, such as our oaks, which extends through an area some seven miles in breadth. You then come to a barren desert region, much of which in winter is covered with snow. From the centre of this district the cone rises up to an elevation of something like 1,100 feet. It is difficult to measure with exactitude the space covered by the base of this mountain, but it is about 87 miles in circumference. But the most remarkable feature of this volcanic pile is not its size, but the character of its structure. The central cone is not the point whence the most disastrous outbursts have occurred. These have often broken through openings in its sides, and especially in the forest region. There are about seventy volcanic peaks in that region, which range from 400 to 700 feet high; besides which there are numerous smaller peaks. Thus you see that Etna, instead of being a single mountain, may be regarded as a cluster of volcanic mountains. I think we shall have no difficulty in understanding how this formation has been brought about. There has been, in the first instance, a central cone, the base of which has been widened by successive eruptions taking place through countless ages. From time to time the volcanic force has burst through lateral points where the resistance was the least, and in this way have been produced the enormous cluster of cones of which Mount Etna now consists. Thus, you see that while Monte Nuovo exhibits a volcano in its simplest form, Etna exhibits a volcano in its most complicated one.

There is another curious illustration of the action of this natural force in the celebrated line of volcanic mountains that was elevated in Mexico within historic times. That chain of mountains is known by the name of Jorullo The diagram before you represents these mountains as they now appear. In this instance there is a plain of considerable extent, which was a fertile region previous to the eruption of 1759. For some two months before that eruption there had been the usual phenomena of earthquakes and subterranean noises. At last a day came when the ground was raised up, and a succession of earthquakes destroyed the whole district, ending in the formation of an enormous chasm, through which came flames and noxious vapours; and, finally, the volcanic products were ejected of which the mountain chain is now composed. Six large cones were formed along the line of the fissure, and the entire surrounding plain became covered with small volcanic hillocks, emitting acid and watery vapours. The highest of the six large cones has an altitude of 1,600 feet, and, as well as the other five, was formed in a few weeks. This is one of the instances in which the volcanic power produced its full results in a very short time, whereas, in the case of Etna and Vesuvius, volcanic action has been repeated from time immemorial to the present day. Jorullo still emits smoke, but there has been no further enlargement since the mountain was thrown up.

I have thus given you a few of the more remarkable instances of earthquakes and volcanic mountains, and the question which now arises is—What are the causes of these phenomena?

Before attempting to answer this question, let me correct the common misconception that the streams of lava are like glowing masses of molten metal. Such is the case to only a limited extent. If you visit Vesuvius during an eruption and examine the moving lava, instead of a flowing stream of red-hot liquid, you see approaching you a huge mound of cinders, which rumbles along with a rattling and crackling sound. If the slope of the mountain is great, this mass moves somewhat rapidly, but in other cases it may take days to move a quarter of a mile. But whence comes this mass of rolling cinders? That question is easily answered. The lava at its first outburst is exposed to the chilling influence of the atmosphere, and it speedily becomes a hard, cindery mass; but below this there presses the flowing lava, which very soon breaks up the hardened crust; and as the broken cinders are full of cavities, and hence much lighter than the fluid lava below, they float upon it. As the latter stream travels

onwards, the hardened cindery mass becomes thicker and more weighty, impeding the progress of the flowing stream, until it finally arrests all further progress: the force becomes expended, and all you have left is a broad stream of hardened and consolidated lava-cinders.

We may now ask, What is the explanation of these phenomena? In the first instance, when men speculated upon the probable cause of these things, they naturally fell back upon the idea that there existed in the interior of the earth a huge central reservoir of molten lava which, from time to time, pumped itself out through volcanic vents. There is no doubt that there was a period when our globe was a fluid-heated mass. What the causes were that made it what it was, I won't venture to say; but that it was once a ball of molten fluid, whirling its way through space, and that the moon was another of the same kind, I have very little doubt. If this were so, the earth, as it slowly cooled, would gradually harden at its surface, but at its centre everything would remain in a fluid condition, from the intensity of its retained heat. It is well known that as we descend into the earth we experience an increase in the temperature, but the rate of this increase varies in different localities, from one degree of Fahrenheit in 35 to one in 70 or even more feet. If the increase of temperature continued in this ratio as we descended, it would be easy to calculate how deep we should have to go to find everything in a molten state. But other elements come in to modify the problem. As we go deeper down the weight of the superimposed mass of earth exerts such a pressure that the compressed matter will not melt so readily as it does at the surface. It requires a much greater heat to melt metals exposed to a high pressure than when no such pressure exists. Owing to our imperfect knowledge of the interior of the globe, we have not the necessary data for estimating accurately the increase of the temperature. The distinguished chemist, Sir Humphrey Davy, advanced a pretty theory to account for these volcanic eruptions. Sir Humphrey having recently discovered the metals sodium and potassium, and which he found to be explosive when in contact with water, assumed that similar metals existed in great quantities in the interior of the earth, and supposed that when water found its way to them explosions took place. Within the last few months an able philosopher, Mr. Mallet, has given us a new and a better hypothesis. This same ingenious observer explained some years ago the movements of the huge waves that often accompany earthquakes, at first retreating from and

then overflowing the land. He showed that any force applied laterally to the earth upon which water rested would travel through these two mediums with very different velocities. The earth would transmit the shock more quickly than the water. If you give a sudden push to a dish containing water, the dish will go forward and leave the water behind it. The latter would retain its original position longer than the dish upon which it rests. Mr. Mallet reasoned that the same effect would be produced upon the sea in the case of an earthquake shock. But such a disturbance of the levels of earth and sea would only be temporary. Water must and will regain its level, and therefore the wave which for a moment retreated from the shore, would return with an additional impetus, and would thus roll upon the land, creating additional destruction to that caused by the earthquake. This simple explanation of Mr. Mallet's is probably the true one. Within the last few months he has further given us what appears to me an exceedingly probable explanation of the origin of volcanic force. That water is mixed up with this origin every physicist now admits. I should have told you that occasionally fish have been ejected from the craters of volcanoes, and we know that fish will not live in cauldrons of boiling lava. Other aquatic objects have likewise been found in volcanic ashes. Thus we have clear proof that water is associated with volcanic action. Our great townsman, Dr. Joule, has demonstrated that any given amount of force always expends itself in a definite amount of heat, and that you cannot destroy a force without producing heat. Mr. Mallet says, and with great probability, that the earth is a cooling globe, and that it cools fastest at the surface. If you have ever made and moulded toffy you may have burnt your fingers, by finding that the mass was scalding hot in the centre when its surface appeared cold and hard. Now, when anything cools it shrinks in size. The earth would cool more rapidly at the poles than at the equator. The result of this unequal cooling would be that some parts of the earth's crust would be harder and denser than other parts; there would be lines of weakness and lines of strength; lines of resistance and lines incapable of resistance. When the surface of the globe was shrinking through this cooling process, that shrinking would occasion a considerable amount of pressure upon its more central portions. So long as the shell was thin the shrinking would only curl or crumple it into little undulating hills and valleys; but when the crust became so thick from cooling that it would no longer bend, then it must break. If you realise some huge wedge of the crust of the globe

thrusting its way down to some lower level, you will readily see that it must produce an immense pressure upon the substances at a yet deeper level. Mr. Mallet has shown that by applying the philosophy of Dr. Joule to the phenomena in question, you obtain a cause equal to the production of heat sufficient to melt any rocks that exist in the interior of the globe. He supposes, therefore, that it is this contraction of the cooling globe, producing local pressure, that has converted portions of the interior of the globe into heated fluids. He believes that the reservoirs of lava thus produced under the surface are local. Then comes the question, Why is this melting of solid rocks followed by the volcanic outbreak? In answering this question we must remember the fact that volcanoes are almost always in the neighbourhood of water. All men agree that the force which has elevated these mountains, and thrown out erupted materials, is precisely the same as that which works your steam-engines in Manchester, namely, steam. Water filters through the fissures in the crust of the earth, and on reaching the local reservoirs of melted lava it is converted into steam; and when the pressure becomes sufficient it rushes out through some vent, forcing up, at the same time, lava, stones, and everything else that comes in its way. Thus we find that a force of the simplest kind, with which we are all familiar, is powerful enough to produce the phenomena of earthquakes and volcanoes.

I have now done. I would only in conclusion again remind you that it is a shortsighted philosophy which sees in these events only calamitous instruments of destruction and evil. While there have been dark days in the history of the world, occasioned by these agencies, on the whole their effect is beneficial. Had it not been for the existence of these volcanic powers, acting upon the crust of the earth in successive ages of its bygone history, nine-tenths of the mineral materials which now give value to the globe, and furnish so many of the comforts and necessaries of life, would have been beyond our reach. But for these eruptive elevations the coal, iron, and most of the other metals would have been beyond the reach of man; like the savages of olden time, we should have had to make our working implements of stone. Rocks that were originally level have by this force been inclined or pitched upon their ends, and even doubled over, as I have seen them amongst the Alpine mountains. In this way the mineral treasures of the earth that would have been buried deep in the earth have been raised to the surface in various parts

of the globe, and thus brought within the reach of man. I will not attempt to read you a lesson in theology on this occasion, because that is not a subject which we introduce here; but I will say, that whether we recognise a personal God, ruling over the universe, and foreseeing from the very beginning what the wants of man would be, or whether we merely regard these phenomena as products of the blind forces of nature—whether we accept the one hypothesis or the other, we must acknowledge that the result has been a wondrous blessing, and one apparently framed to meet the wants and increase the enjoyments of mankind.

MODERN SAVAGES.

A LECTURE, delivered in the Hulme Town Hall, Manchester, on Wednesday, December 9th, 1874.

By Sir JOHN LUBBOCK, Bart., M.P., F.R.S.

THE subject on which I have been requested to address you this evening is one of much interest, but also of such vast extent, that I shall make no apology for entering at once upon it, without any introductory remarks. I will only observe that I do not propose to describe the arms or implements, houses or boats, food or dress, of savages; all, no doubt, very interesting, but which time will not permit me to approach. My object will rather be, if possible, to illustrate the mental condition and ideas of the lower races of men—a subject necessarily of great interest to the philosopher, but also of immense practical importance to an empire like ours, which extends to every quarter of the globe, and contains races of men in every stage of civilisation.

Even those who consider that man was civilised from the beginning, and who look upon savages as the degenerate descendants of much superior parents, must still admit that our ancestors were once mere barbarians, and may find, therefore, much interest in this study; but it no doubt appears far more important to those who think, as I do, that the primitive condition of man was one of barbarism, and that the history of the human race has on the whole been one of progress.

I do not, of course, suppose that every people must necessarily advance; but those who do not will assuredly be replaced, sooner or later, by more worthy races. Nor do I mean that our modern savages, in all respects, reproduce the condition of our ancestors in early times; on the contrary, even the Australians have now codes of laws and rules, which have grown up gradually, and cannot have existed originally. I feel satisfied, however, that from the study of modern savages we can gain a correct idea of man as he existed in ancient times, and of the stages through which our civilisation has been evolved.

As regards their habits, indeed, and the material conditions of life, savages differ greatly. The Esquimaux, in the land of ice and seals; the hunters of the American forests and prairies; the beautiful islanders of the still more beautiful Islands in the Pacific; the Tartars of the Siberian steppes; the negroes of tropical Africa—necessarily differ greatly in their diet, their clothes, their houses, &c.; but, on the other hand, as regards ideas and customs, the case is different, and we find very remarkable similarities, even in the most distinct races and the most distant regions of the globe.

I propose, therefore, more especially to call your attention to the social, or family relations, and the religious ideas of the lower races. Our ideas of relationship, founded as they are on marriage, seem so natural and obvious, that we are at first inclined to regard them as having been original and common to man. This, however, as I shall attempt to show you, would be a mistake. Indeed, the position of woman is, among the lower savages, melancholy in the extreme, and precludes all those tender and sacred feelings to which so much of our best and purest happiness is due.

Again, the religion—if so it can be called—of savages differs greatly from, nay, in some respects, is the very opposite of ours.

The whole mental condition of the savage is, indeed, so dissimilar from ours that it is often very difficult for us to follow what is passing in his mind, or to understand the motives by which he is actuated. Many things appear natural, and almost self-evident to him, which produce a very different effect upon us. "What," said a *negro* once to *Burton*, "am I to starve while my sister has children whom she can sell?" Thus, though savages always have a reason, such as it is, for what they do and what they think, these reasons often seem to us irrelevant, or absurd. Moreover, the difficulty of understanding what is passing in their minds is, of course, much enhanced by the differences of language.

These have produced many laughable mistakes. Thus, when *Labillardière* inquired of the Friendly Islanders (whose language we now perfectly understand) what was their word for 1,000,000, they seem to have thought the question absurd, and gave him a word which has no meaning; when he asked for 10,000,000 they said "looole," which I will leave unexplained; for 100,000,000, "laounoua," which means "nonsense;" while for still higher numbers, they gave him, in joke, certain coarse expressions which he has gravely recorded in his table of numerals.

A mistake made by *Dampier* led to more serious results. He had met some Australians, and apprehending an attack, he says,

"I discharged my gun to scare them, but avoided shooting any of them, till, finding that we were in great danger from them, and that though the gun had a little frightened them at first, yet they had soon learnt to despise it, tossing up their hands, and crying, 'Pooh, pooh, pooh,' and coming on afresh with a great noise, I thought it high time to charge again, and shoot one of them, which I did." Thus, this wretched savage lost his life because Dampier did not remember that "pooh, pooh," or "puff, puff," is the name which savages, like children, apply to guns.

Again, the modes of salutation among savages are sometimes very curious, and their modes of showing their feelings quite unlike ours.

Kissing seems to us so natural an expression of affection, that we should expect to find it all over the world. Yet it was unknown to the Australians, the New Zealanders, the Papouans, the West African negroes, and the Esquimaux.

The Polynesians and the Malays always sit down when speaking to a superior. In some parts of Central Africa it is considered respectful to turn the back to a superior. Captain Cook asserts that the inhabitants of Mallicolo, an island in the Pacific Ocean, show their admiration by *hissing*. The Todas of the Neilgherry Hills, in India, are said to show respect by raising the open right hand to the brow, resting the thumb on the nose. It is asserted that among the Esquimaux it is customary to pull a person's nose as a compliment. A Chinaman puts on his hat when he should take it off; and among the same curious people a coffin is regarded as a neat and appropriate present for an aged person, especially if in bad health.

Under these circumstances, we cannot wonder that we have very contradictory accounts of the character and mental condition of savages. Nevertheless, by comparing together the accounts of different travellers, we can to a great extent eliminate these sources of error; and we are much aided in this by the remarkable similarity between very different races. So striking, indeed, is this likeness, that different races, in similar stages of development, often present more features of resemblance to one another than the same race does to itself in different stages of its history.

Some ideas, indeed, which seem to us at first inexplicable and fantastic, are yet very widely distributed. I will only allude to two. Probably every Englishman who had not studied other races, would be astonished to meet with a nation in which, on the birth of a baby, the father, and not the mother, was put to bed and nursed. Yet, though this custom seems so ludicrous to us, it prevails very

widely. Dobritzhoffer says that among the "Abigrones of South America, no sooner do you hear that a woman has borne a child, than you see the husband lying in bed, huddled up with mats and skins, lest some rude breath of air should touch him, and for a number of days abstaining religiously from certain viands; you would swear it was he who had had the child. . . . . I had read about this in old times, and laughed at it, never thinking I could believe such madness; and I used to suspect that this barbarous custom was related more in jest than in earnest; but at last I saw it with my own eyes among the Abigrones." Other travellers mention the existence of a similar custom in Greenland, in Kamtschatka, in parts of China, in Borneo, in the north of Spain, in Corsica, and in the south of France, where it was called "faire la couvade."

Another curious idea very prevalent among savages is their dread of having their portraits taken. The better the likeness, the worse they think for the sitter; so much life could not be put into the copy, except at the expense of the original. Once, when a good deal annoyed by some of the North American Indians, Kane got rid of them instantly by threatening to draw them if they remained. Catlin tells an amusing but melancholy anecdote in illustration of this feeling among the same people. On one occasion he was making a likeness of a chief named Mahtocheega in profile. This, when observed, excited much commotion among the Indians. "Why was half his face left out?" they asked. "Mahtocheega was never afraid to look a white man in the face." Mahtocheega himself does not seem to have taken any offence, but Shonka, a hostile chief, took occasion to taunt him. "The Englishman," he said, "knows that you are but half a man; he has painted but one half of your face, and knows that the rest is good for nothing." This taunt led to a fight, in which poor Mahtocheega was killed; and the whole affair was very unfortunate for Mr. Catlin, who had much difficulty in making his escape, and lived some time in fear of his life.

We cannot wonder that writing should appear to the savage even more mysterious and uncanny than drawing. Carver allowed the Canadian Indians to open a book whenever they pleased, and then told them the number of leaves on each side. The only way they could account for this, he says, "was by concluding that the book was a spirit, and told me whatever I asked." Further south, the Minatarrees, seeing Catlin intent over a copyof the *New York Commercial Advertiser*, were much puzzled, but at length

concluded that it was a cloth for sore eyes. One of them eventually bought it at a high price.

This belief in the mysterious character of writing has led to its being used in various parts of the world as a *medicine*. The Central Africans are a religious people according to their lights, and have great faith in the efficacy of prayers. When any one is ill they write a text out of the Koran on a board, wash it off, and make the patient drink it. The French traveller, Caillie, met with a man who had a great reputation for sanctity, and who made his living by writing prayers on a board, washing them off, and then selling the water, which was sprinkled over various objects, and supposed to improve and protect them. It was soon observed that the charms were no protection from firearms, but that did not in the least weaken the faith in them, because they said as guns were not invented in Mahomet's time, he naturally provided no specific against them.

Savages are passionately fond of ornaments. If in the very low races the women are often wholly undecorated, this is only because the men keep all the ornaments to themselves. As a general rule we may say that races inhabiting hot climates ornament themselves; those of colder countries, their clothes. In fact, all savage races who leave much of their skin uncovered delight in painting themselves in the most brilliant colours.

Another subject on which savages entertain notions very different from ours, is that of relationships on marriage and on the family. We regard a child as related equally to its father and its mother: we make no difference between a father's brother and a mother's brother on the one hand—a father's sister and a mother's sister on the other; they are respectively uncles and aunts. But among savages it is not so. As we descend in the scale of civilisation, the family diminishes, and the tribe increases, in importance. The relationship to the clan almost supersedes that to the family. The position of the women is very unfortunate. They are treated like slaves, or almost like domestic animals. Thus, in Australia, "little real affection exists between husband and wife, and young men value a wife principally for her services as a slave; in fact, when asked why they are anxious to obtain wives, their usual reply is that they may get wood, water, and food for them, and carry whatever property they possess." So little did affection enter into the idea of marriage, so little were the feelings of the woman consulted, that among the ruder races of men we find it the custom for men to carry off their wives by force. Indeed, in

many cases marriage within the tribe was forbidden, and all over the world we find traces of the ancient custom of marriage by capture. In some regions, indeed, this is still a rude reality. In others the mimicry of force alone remains.

Among the Kalmucks of Central Asia the marriage ceremony is very romantic. The girl is put on a horse, and rides off at full speed. When she has got enough start, the lover starts in pursuit. If he catches her she becomes his wife, but if he cannot overtake her the match is broken off; and we are assured—which I can well believe—that no Kalmuck girl was ever caught against her will. Again, among the Ahitas of the Philippine Islands, when a man wishes to marry a girl, her parents send her, before sunrise, into the woods. She has an hour's start; after which the lover goes to seek her. If he finds her and brings her back before sunset, the marriage is acknowledged; if not, he must abandon all claim to her.

The aborigines of the Amazon valley, says Wallace, "have no particular ceremony at their marriages, except that of always carrying away the girl by force, or making a show of doing so, ven when she and her parents are quite willing." M. Bardel mentions that among the Indians round Conception, in Chili, on the other side of the Andes, after a man has agreed on the price of a girl with her parents, the recognised mode of proceeding is that he surprises her, or is supposed to do so, and carries her off to the woods for a few days, after which the happy couple return home. As regards Europe we find just the same thing: the Romans had a similar custom, and traces of it occur in Greek history. In North Friesland the bride makes a show of resistance, and is lifted by mock force into the waggon which is to take her home. Hence, no doubt, the custom of lifting the bride over the doorstep, which occurs, or did occur, among the Romans, the Redskins of Canada, the Chinese, and the natives of Abyssinia. Hence, also, perhaps our custom of the honeymoon; and hence also may be, as Mr. M. Lennan has suggested, that the slipper thrown in mock anger after the departing bride and bridegroom. The latter suggestion is indeed very doubtful; still it is remarkable how persistent are all customs and ceremonies connected with marriage. Thus our "bridecake," which so invariably accompanies a wedding, may be traced back to the old Roman form of marriage by "confarreatio," or eating together.

At first the feeling of clanship prevailed rather than that of family, and children were regarded as related to the tribe rather than to

their parents; secondly, they were considered to be related to the mother, but not to the father; thirdly, to the father, but not to the mother; lastly, and lastly only, as among ourselves, to both father and mother. We see therefore that the lowest savages are very deficient in the idea of marriage and of family, and that the position of women is wretched in the extreme. The ideas of relationship founded on marriage, have only gradually been acquired, and thus civilisation has raised the position of woman, and made her a helpmeet instead of a slave; has purified and softened all the conditions of social life. The higher position of woman is one of the points in which we see the inestimable advantage of civilisation over barbarism.

[Several curious diagrams were here referred to. The first illustrated symbolically the census of an Indian tribe made for the United States Government; others typified the lives of certain chiefs. Perhaps the most interesting was a copy of an Indian petition to the President of the United States, praying for fishing rights in Lake Superior.]

The religious condition of the lower races of mankind is one of the most difficult, although at the same time most interesting, portions of my subject. It is most difficult, partly because it is far from easy to communicate with men of a different race on such an abstruse subject, partly because many are reluctant to discuss it, but mainly because, even among those nominally professing the same religion, there are always in reality great differences: individuals—as I shall endeavour to show you is also the case with nations—acquiring continually grander, and therefore more correct, ideas as they rise in the scale of civilisation. Still, as new religious ideas arise they do not destroy, but are only superinduced upon the old ones. Thus the religion of the ancestors become the nursery tales of their descendants, and the old Teutonic deities of our forefathers are the giants and demons of our children.

It has hitherto been usual to classify religions, either according to the name of the founder or the nature of the objects worshipped. Thus one division of the lower religions has been into

Fetichism, defined as the worship of material substances;

Sabæism, that of the heavenly bodies, the sun, moon, and stars; and

Heroism, or the deification of men after death.

This and other similar systems are simple, and have certainly some advantages, especially as regards the lower races of men and the lower forms of religion. It is not, however, natural; there is

no real difference between the worship of the sun and that of rock or lake. No doubt to us the sun seems the grander deity, but of the main facts on which that opinion rests the savage is entirely ignorant.

The true classification of religion should, as it seems to me, rest, not on the mere object worshipped, but on the nature and character ascribed to the Deity. It is a much-disputed question, into which I will not now enter, whether the lowest races of men have any religion or not. However this may be, it is at least clear that the religion of savages is very unlike that of most advanced races. Indeed, in many respects it is very opposite. Their deities are evil, not good; they may be forced into compliance with the wishes of man; they require bloody, and rejoice even in human, sacrifices; they are mortal, not immortal—part of nature, not the creators of the world; they are to be approached by dances rather than by prayers; and often approve of sin rather than of what we esteem as virtue.

The ideas of religion among the lower races of man are intimately associated with, if, indeed, they have not originated from, the condition of man during sleep, and especially from dreams. Sleep and death have always been regarded as nearly related to one another. Thus, in classical mythology, Somnus, the god of sleep, and Mors, the god of death, were both fabled to have been the children of Nox, the goddess of night. So also the savage would naturally look on death as a kind of sleep; and would expect and hope—hoping on even against hope—to see his friend awake from the one as he had often done from the other. Hence, probably, one reason for the great importance ascribed to the treatment of the body after death. But what happens to the spirit during sleep? The body lies lifeless, and the savage not unnaturally concludes that the spirit has left it. In this he is confirmed by the phenomena of dreams; and, consequently, to the savage they have a reality and an importance which we can scarcely appreciate. During sleep the spirit appears to desert the body; and as in our dreams we seem to visit other countries and distant regions while the body remains, as it were, lifeless, the two phenomena were naturally placed side by side, and regarded as the complements one of the other. Hence the savage considers the events in his dreams as real as those which happen when he is awake, and hence he naturally feels that he has a spirit which can quit the body, if not when it likes, at least under certain circumstances.

So strong was the North American faith in dreams, that on one occasion, when an Indian had dreamt that he was taken captive and tortured, he induced his friends to make a mock attack upon him, and actually submitted to very considerable suffering, in the hope that he would thus fulfil his dream.

The Greenlanders also believe in the reality of dreams, and think that at night their spirit actually goes hunting, visiting, courting, and so on. It is, of course, obvious that the body takes no part in these nocturnal adventures, and hence it seems to them natural to conclude that they have a spirit which can quit the body. Lastly, when they dream of their departed friends or relatives, savages firmly believe that they are visited by the spirits of the dead, and hence believe, not, indeed, in the immortality of the soul, but in the existence of a spirit which survives, or may survive, the body. Again, savages are seldom ill. Their sufferings generally arise from wounds; their deaths are generally violent. As an external injury received, say, in war, causes pain, so, when they suffer internally, they attribute it to some enemy within them. Hence, when an Australian, perhaps after too heavy a meal, has his slumbers disturbed, he is at no loss for an explanation, and supposes that he has been attacked by some being whom his companions could not see. This is well illustrated in the following passage from Captain Wilkes's "Voyage." "Sometimes," he says, "when the Australian is asleep, *Koin*, as they call this spirit, seizes upon one of them, and carries him off. The person seized endeavours in vain to cry out, being almost strangled. At daylight, however, Koin departs, and the man finds himself again safe by his own fireside." Here it is evident that Koin is a personification of the nightmare.

In other cases the belief that man possesses a spirit seems to have been suggested by the shadow. Thus, among the Fijians, "some," says Mr. Williams, "speak of man as having two spirits. His shadow is called the 'dark spirit,' which they say goes to Hades. The other is his likeness reflected in water or a looking-glass, and is supposed to stay near the place in which a man dies. Probably, this doctrine of shadows has to do with the notion of inanimate objects having spirits. I once placed a good-looking native suddenly before a mirror. He stood delighted. 'Now,' said he softly, 'I can see into the world of spirits.'" But though spirits are naturally to be dreaded on various accounts, it by no means follows that they should be conceived as necessarily wiser or more powerful than man. Of this, our spirit-rappers and table-

turners afford us a familiar illustration. So also the natives of the Nicobar Islands put up scarecrows round their villages to frighten away hostile spirits. The natives of Kamtschatka insult their deities if their wishes are unfulfilled. They even feel a contempt for them. "If Kutka," they say, "had not been stupid, would he have made inaccessible mountains, and too rapid rivers?"

The Lapps made images of their gods, putting each in a separate box, on which was written the name of the deity, so that each might know its own box.

The Kyoungtha of Chittagong are Buddhists. Their village temples contain a small stand of bells, and an image of Boodh, which the villagers generally worship morning and evening, "first," as Captain Lewin states, "ringing the bells to let him know they are there." The Sinto temples of the Sun Goddess in Japan also contain a bell, intended, as Bishop Smith tells us, "to arouse the goddess and to awaken her attention to the prayers of her worshippers."

Many other illustrations might be given, but these are sufficient to show how low and degraded is the savage conception of the Divine nature. Gradually, however, as the human mind expands, it becomes capable of higher and higher realisations.

The religion of the Australians, if it can be so called, consists of a belief in the existence of ghosts, or spirits, or, at any rate, of evil beings who are not mere men. This belief cannot be said to influence them by day, but it renders them very unwilling to quit their camp fire by night, or to sleep near a grave. They have no idea of creation, nor do they use prayers; they have no religious forms, ceremonies, or worship. They do not believe in a Supreme Deity, or in the immortality of the soul; nor is morality in any way connected with their religion.

An interesting account of the religious condition of the northern Australians has been given by a Mrs. Thomson, a Scotchwoman, who was wrecked on that coast, and lived alone with the natives for nearly five years, when she was rescued by an English ship. The Australians all over the continent have an idea that when the blacks die they turn into whites. Mrs. Thomson herself was taken for the ghost of a woman named Giom; and when she was teased by the children, the men would often say, "Leave her alone, poor thing! She is nothing—only a ghost." This, however, did not prevent a man named Baroto making her his wife, which shows how little is really implied in the statement that the Australians believe in the existence of spirits. In reality they do no more

than believe in the existence of men slightly different from and somewhat more powerful than themselves.

The Fetichism of the negro is a step in advance, because the influence of religion is much raised in importance. Nevertheless, from one point of view, Fetichism may be regarded as an ante-religion; for the negro believes that, by means of the fetish, he can coerce and control the deity. In fact, Fetichism is mere witchcraft. We know that all over the world would-be magicians think that if they can obtain a part of an enemy, or even a bit of his clothing, they thus obtain a control over him. Nay, even the knowledge of the name is supposed to confer a certain power. Hence the importance which savages attach to names. Thus, for instance, the true name of the beautiful Pocahontas, a celebrated Canadian chieftainess, was Matokes; but this name was carefully concealed from the English, lest it should give them a power over her. For the same reason the Romans carefully concealed the name of the patron saint of their city. In other cases it was thought sufficient to make an image to represent the original. Thus, even in the eleventh century, and in Europe, some unfortunate Jews were accused of murdering a certain Bishop Eberhard, by making a wax figure to represent him, and then burning it, whereby the bishop died. This, indeed, was a common form of witchcraft.

Now Fetichism seems a mere extension of this belief. The negro supposes that the possession of a fetich, representing a deity, makes that deity his slave. A fetish, therefore, differs essentially from an idol. The one is intended to raise man to the contemplation of the deity; the other to bring the deity within the control of man. Aladdin's lamp is a familiar instance of a fetich; and, indeed, if witchcraft be not confused with religion, Fetichism can hardly be called a religion.

The low religious conceptions of the negroes are well illustrated by the general belief that the fetich sees with its eyes as we do; and so literally is it the actual image which is supposed to see, that when the negro is about to do anything of which he is ashamed, he hides his fetich in his waistcloth, so that it may not be able to see what is going on. Fetichism, strictly speaking, has no temples, idols, priests, sacrifices, or prayer. It involves no belief in creation or in a future life, and *à fortiori* none in a state of future rewards and punishments. It is entirely independent of morality.

The next stage in religious progress is that which may be called

Totemism. The savage does not abandon his belief in Fetichism, from which, indeed, no race of man has yet entirely freed itself; but he superinduces on it a belief in beings of a higher and more mysterious nature. In this stage everything is deified—stones, rivers, lakes, mountains, the heavenly bodies, even animals and plants.

Various theories have been suggested to account for the origin of the deification of such objects. I believe that it arose principally in this way. A chief, being named after some tree or animal, say the black bear or the eagle, his family would naturally take the same name. They would then come to look on the animal after which they were named, first, with interest, then with respect, and at length with a sort of awe.

In Australia we seem to find the Totem, or, as it is there called, the "kobong," in the very process of deification. Sir George Grey tells us that each family takes some animal or plant as its sign or "kobong." No native will intentionally kill or eat his "kobong," which shows that there is a mysterious feeling connected with it; but we are not told that in Australia the "kobong" is regarded as a deity. In America, on the other hand, the redskins worship their Totem, from which they believe themselves to be actually descended.

It is somewhat more difficult to understand the deification of inanimate objects. In fact, however, savages scarcely believe in the existence of inanimate objects. Chapman mentions that the bushmen in South Africa thought his big wagon was the mother of his small one. Hearne tells us that the North American Indians never hang up two nets together, for fear they should be jealous of one another, and that they prefer a hook which has caught a big fish to fifty which have never been tried. The South Sea Islanders not only believed that animals had souls, but also that this was the case with inanimate objects. Hence the savage broke the weapons, &c., buried with the dead, so that their souls might accompany that of their master to the land of spirits. Hence, also, on one occasion the king of the Koussa Kaffirs, having broken a piece of iron from a stranded anchor, and dying soon after, the Kaffirs immediately concluded that the anchor was alive and had killed their king. Some such accident probably gave rise to the ancient Mohawk notion that some great misfortune would befall anyone who spoke while crossing Saratoga Lake. A strong-minded Englishwoman on one occasion purposely did so, and after landing, rallied her boatman on his

superstition; but I think he had the best of it after all, for he at once replied that the Great Spirit was merciful, and knew that a white woman could not hold her tongue.

The South Sea Islanders, who represent a distinctly higher phase of civilisation than the hill tribes of Hindostan, or the Red Indians of North America, present us also with a higher form of religion. Their deities are conceived as more powerful. In many islands there are traditions of a powerful being who raised the land from below the waters; and in Tonga, until lately, it is said that the very hook was shown with which this was effected. Still the deities cannot be regarded as creators, because both earth and water existed before them. Neither was the religion of the South Sea Islanders connected with morality. Their deities were not supposed to reward the good or to punish the evil. In the Tonga and other islands, indeed, the common people were not supposed to have souls at all. In Tahiti, the natives believed in a future life, and even in the existence of a separation between the spirits, some going to a much happier place than others. This, however, was not considered to depend on their conduct during life, but on their rank—the chiefs going to the happier, the remainder of the people to the less desirable, locality. The Feejeeans believe that as they die such will be their condition after death. Moreover, the road to Mbulu, or heaven, is long and difficult; many souls perish by the way, and no diseased or infirm person could possibly succeed in overcoming all the dangers of the road. Hence, as soon as a man feels the approach of old age, he notifies to his children that it is time for him to die. A family consultation is then held, a day appointed, and the grave dug. Mr. Hunt gives a striking description of such a ceremony once witnessed by him. A young man came to him and invited him to attend his mother's funeral, which was just going to take place. Mr. Hunt accepted the invitation, and joined the procession; but, surprised to see no corpse, he asked where the mother was, when the young man pointed out his mother, who, in Mr. Hunt's words, was walking along "as gay and lively as any of those present." When they arrived at the grave, she took an affectionate farewell of her children and friends, and then cheerfully submitted to be strangled. So general, indeed, was this custom in the Feejee Islands, that in many villages there were literally no old people, all having been put to death; and, if we are shocked at the error which led to such dreadful results, we may at least see something to admire in the firm faith with which they acted up to their religious belief.

It will be observed that up to this stage religion is entirely deficient in certain characteristics with which it is generally regarded as intimately associated. The deities are mortal, they are not creators; no importance is attached to true prayers; virtue is not rewarded, nor vice punished; there are no temples, or priests; and, lastly, there are no idols. Up to this stage, indeed, we find the same ideas and belief scattered throughout the whole world among races in the same low stage of mental development. From this point, however, differences of circumstance—differences of government—differences of character—materially influence the forms of religious belief. Nations of cold climates regard the sun as beneficent; those of the tropics consider him as evil; hunting races worship the moon; agriculturists the sun. Again, in free communities thought is free, and consequently progressive; despots, on the contrary, by a natural instinct, endeavour to strengthen themselves by the support of spiritual terrors, and hence favour a religion of sacrifices and of priests, rather than one of prayer and meditation.

Lastly, the character of the race impresses itself on the religion. Poetry especially exercises an immense influence, as, for instance, has been well shown by Max Müller and Cox to have been the case with the Greeks, the names of the Greek gods reappearing in the earlier Vidic poetry as mere words denoting natural objects. Thus "Dyans" in ancient Sanscrit means simply the sky, and the expression the "sky thunders" meant originally no more than it does with us. The Greeks and Romans, however, personified Dyans or Zeus; thus came to regard him as a deity, the God of Thunder, the Lord of Heaven, and thus built up a whole mythology out of what were at first mere poetical expressions. Time, however, does not permit me to enter on this interesting part of the subject. I trust, however, that I have said sufficient to show that the opinions of the lower savages as regards religion differ essentially from those prevalent among us. Their deities are scarcely more powerful than themselves; they are evil, not good; they are to be propitiated by sacrifices, not by prayer; they are not creators; they are neither omniscient nor all-powerful; they neither reward the good nor punish the evil; far from conferring immortality on man, they are not even in all cases immortal themselves.

Where the material elements of civilisation developed themselves without any corresponding increase of knowledge—as, for instance, in Mexico and Peru—a more correct idea of divine

power, without any corresponding enlightenment as to the divine nature, led to a religion of terror, which finally became a terrible scourge of humanity. Gradually, however, an increased acquaintance with the laws of nature enlarged the mind of man. He first supposed that the Deity fashioned the earth, raising it out of the water and preparing it as a dwelling-place for man, and subsequently realised the idea that land and water were alike created by divine power. After regarding spirits as altogether evil, he rose to a belief in good as well as in evil deities, and, gradually subordinating the latter to the former, worshipped the good spirits alone as gods—the evil sinking to the level of demons. From believing only in ghosts, he came gradually to the recognition of the soul. At length, uniting this belief with that in a beneficent and just Being, he connected morality with religion—a step the importance of which it is scarcely possible to overestimate. Thus we see that, as men rise in civilisation, their religion rises with them—that, far from being antagonistic to religion, without science true religion is impossible.

The Australians dimly imagine a being spiteful and malevolent, but weak, and dangerous only in the dark. The negro's deity is more powerful, but not less hateful; invisible, indeed, but subject to pain—mortal, like himself, and liable to be made a slave of man by enchantment The deities of the South Sea Islanders are some good, some evil; but, on the whole, more is to be feared from the latter than to be hoped from the former. They fashioned the land, but are not truly creators, for earth and water existed before them. They do not punish the evil, nor reward the good. They watch over the affairs of men; but if, on the one hand, witchcraft has no power over them, neither on the other can prayer influence them—they require to share the crops or the booty of their worshippers.

Thus, then, every increase in science—that is, positive and ascertained knowledge—brings with it an elevation of religion.

Nor is this progress confined to the lower races. Even within the last century, science has purified the religion of Western Europe by rooting out the dark belief in witchcraft, which led to thousands of executions, and hung like a black pall over the Christianity of the Middle Ages. Yet in spite of these immense services which science has confessedly rendered to the cause of religion, there are still many who look on it as hostile to religious truth, forgetting that science is but exact knowledge, and that he who regards it as incompatible with his religion, practically admits

that his religion is untenable. No; the true spirit of faith looks on the progress of science, not with fear but with hope, knowing that science can influence our religious conceptions for good only: it may purify and elevate, it has no tendency to destroy.

Whether, then, science is destined, as some suppose, to modify the present religious views or not—a question into which I do not now wish to enter—no one ought on that account to regard it with apprehension or with distrust. Far from it. We must be prepared to accept any conclusions to which the evidence may lead; not in the spirit of resignation or of despair, but in the certain faith that every discovery of science, even if it may conflict with our present opinions, and with convictions which are dear to us, will open out to us more and more the majestic grandeur of the universe in which we live, and thus enable us to form grander and therefore truer conceptions of religious truth. So far, indeed, from being hostile to religion, we need only study history to perceive the important service which science has rendered to the cause of religious truth—to satisfy ourselves that a better acquaintance with the beautiful world in which we live would not only diminish the physical evils from which we suffer, and thus add to the general happiness and comfort, but would also tend to raise our moral and spiritual nature, to elevate and purify the whole character of man.

Palestine Exploration:

THE ANCIENT AND MODERN WATER SUPPLY OF JERUSALEM.

A LECTURE, delivered in the Hulme Town Hall, Manchester, on Wednesday, December 16th, 1874,

BY MAJOR WILSON, R.E., F.R.S.

THE subject upon which I have been asked to address you this evening—"Palestine Exploration"—is so large that I could not possibly do justice to it in the time at my disposal. I have, therefore, selected one particular branch of the exploration, the water supply of Jerusalem, and I hope to be able to add a few words on the nature and object of the excavations which have been made in the Holy City.

Some ten years ago the sanitary state of Jerusalem attracted considerable attention. That city, which the Psalmist had described in loving terms as "the joy of the whole earth," had become one of the most unhealthy places in the world, and it was known that this change was due, partly to the vast accumulation of rubbish within the city, and partly to the inferior quality of the water supply. With the rubbish it was hardly possible to deal, but the water supply seemed an easier matter, and several schemes were proposed for its improvement. Before, however, any of these could be carried out, it was necessary to obtain an accurate plan of the city; and this, having been represented to the Lady Burdett Coutts, who is ever ready to promote good works, she at once placed the requisite funds in the hands of a committee of gentlemen interested in Jerusalem. The survey was made by myself and a party of Royal Engineers from the Ordnance Survey, under the direction of Major-General Sir Henry James, and I am able to show you this evening some of the published results. The success of the survey, and certain discoveries which we were fortunately able to make during its progress, aroused considerable interest in England, and led to the formation of the Palestine Exploration Fund, which is now engaged in making a complete survey of the whole country.

It is, perhaps, hardly necessary to explain that Palestine is a narrow tract of country lying along the extreme eastern coast of the Mediterranean, and that a range of hills from 2,500 to 4,000 feet high runs through it, in a direction parallel to the sea, from Lebanon on the north. to the desert on the south. In the midst of these hills lies Jerusalem, situated on a spur or plateau, which is bordered by two ravines bearing the familiar names of Kedron and Hinnom. The ravines rise within a short distance of each other, and encircling the plateau, the Kedron on the north and east, the Hinnom on the west, run together south of the city, not far from the well of Joab. Both valleys are at first mere depressions of the ground, but after running about a mile and a half they fall more rapidly, and at Joab's well are 670 feet below their starting point. A third valley, known as the Tyropœon, rises well up in the plateau, and, after passing through the city and dividing it into two unequal halves, joins the Kedron at Siloam. On the eastern of these two halves, Mount Moriah, once stood the temple, and on the western, which is 120 feet higher than Moriah, were situated Herod's palace, with its three great towers, and what Josephus calls the upper city. A short ravine, along the side of which the first or most ancient wall of the city was built, runs down to the Tyropœon from the west (Jaffa gate); and there is also a fourth distinct valley, which, rising in the eastern portion of the plateau, joins the Kedron, after receiving a small tributary from the west that has an important bearing on the site of the temple.

The sides of the valleys of Kedron and Hinnom are now encumbered with rubbish, but they are sufficiently steep to be difficult of access, and every here and there places are found where the rock has been scarped or cut perpendicularly downwards to give additional security. It was possibly in these natural defences, which protect the city on the south, east, and west, that the Jebusites trusted when they boasted to King David, "Thou wilt not come in hither; the blind and lame shall drive thee back." The only side upon which Jerusalem could be attacked with any chance of success was on the north; and here, as Josephus informs us, it was defended by three walls of great strength. The present bed, or bottom of the Kedron valley, is 38½ feet above its true one; the Tyropœon is filled up to a depth of 107 feet; whilst in the fourth valley—the very existence of which escaped the notice of travellers until recent years—there is no less than 125 feet of rubbish.

The plateau on which the city is situated slopes uniformly to the south-east, and contains about 1,000 acres; it is composed of white, yellow, and buff limestones, of the age of our English chalk; and the arrangement of the strata, which dip to the E.S.E. at about 10°, has an important bearing on the water supply. The upper beds, from 1ft. 6in. to 4ft. in thickness, provide an extremely hard compact stone, which I will call for convenience by its Arab name, "Missae," whilst the lower, some 40 feet in thickness, consist of a soft white stone, called "Malaki;" and it is in this latter bed that most of the ancient tombs and cisterns at Jerusalem have been excavated. The strata are much broken and cracked, so that the rain readily sinks into the ground, and finds its way downwards through a thousand hidden channels, to be given out at a lower level. The general direction of this underground flow, and of the surface drainage of the plateau, is, as you will see by the map, towards Joab's well, below the junction of the two principal ravines, Kedron and Hinnom.

It was at one time supposed that the quantity of rain which fell at Jerusalem each year was very large, from fifty to eighty inches, but the average annual rainfall is really about nineteen inches—not more than half that of Manchester—and the rainy season is spread over the winter months from November to March; during the remaining months even a slight shower is of the rarest occurrence, and the heavens become, to use the graphic language of the Bible, as "brass," and the earth as "iron." Every three or four years there is a fall of snow, which lies on the ground for a day or two; and, on the other hand, there is occasionally an almost total failure of rain. The number of cisterns and reservoirs which were excavated or built for the collection of the rainfall, and the skill exhibited in the construction of the conduits that brought water into the city, show pretty clearly that there has been no material change in the climate or in the quantity of rain since the days of the Jewish monarchy.

The *modern* supply of water is derived from springs, wells, cisterns, pools or reservoirs, and aqueducts.

Springs.—There is only one true spring at Jerusalem, the "Fountain of the Virgin," on the west side of the Kedron ravine; and it has this peculiar feature that, in addition to a constant though small flow, there is an intermittent flow which consists in a sudden increase to the ordinary one. In winter there are from three to five flows each day: in summer two; later on, in autumn,

only one; but after a dry winter the flow takes place only once in three or four days. The water is conveyed from the spring to Siloam by a passage cut in the rock, and thence runs down to irrigate some gardens. Its taste is slightly salt, and decidedly unpleasant, owing chiefly to the fact that the water has filtered through the mass of rubbish and filth on which the city stands. This peculiarity in the taste is intensified at Siloam, as the water passes over a slimy deposit from two to three inches deep, which covers the bottom of the passage; and the people make matters worse by bathing and washing their clothes in the same place from which they draw water for drinking purposes. The passage between the spring and Siloam is 1,700ft. long, about two feet wide, and varies in height from 1ft. 10in. to 16ft. The lower portion is not easy to pass through, especially if the spring commences to flow whilst the explorer is engaged in making the attempt—an event which happened to myself on my first visit. In connection with this passage, Captain Warren, during his excavations, opened out a rock-hewn canal, which ran for some distance due west, with a slight fall, so that the water from the spring could flow down to the western end, where a shallow basin had been excavated to receive it. From this basin a circular shaft led upwards to a great corridor, excavated in the rock, whence a flight of steps gave access to the surface at a point, on that portion of Moriah known as Ophel, which must have been well within the ancient walls of the city. It was thus possible for the Jews, on the approach of an enemy, to close or "seal" the spring with blocks of stone, and at the same time procure a supply of water for their own use by means of the shaft or well within the walls.

Whilst building a convent, to the north of the Temple area, on the shoulder of the hill called Bezetha, which is really a northern continuation of Mount Moriah, a supply of water was met with at the northern end of a remarkable vaulted passage, which, as it had the peculiar taste of the water of Siloam, was at once asserted to be a living spring in connection with that fountain. So far from this being the case, the water was found, on examination, to derive its flavour from a great mass of sewerage which was only separated from it by a heap of loose rubbish; whilst the supply was kept up by the leakage of cisterns, the influx of fresh sewerage, and the drainage of an old aqueduct, that at one time brought water from the north, and passed to the Temple area through the vaulted passage.

Wells.—The only real well is Bir Eyub, or Joab's well, a short distance below the junction of the Kedron and Hinnom ravines. It has a depth of 125 feet, and a large chamber has been excavated at the bottom to act as a collector, for the supply is entirely derived from the drainage of the two valleys and from the water that runs in between the beds of limestone. An attempt has been made to stop out the surface drainage, which is charged with impurities; but it has not proved very successful, and the water retains a decidedly salt taste. From this well the poor of the city obtain their water when, towards the end of summer, the cisterns run dry; but it lies about 500 feet below the city, and the raising and carriage of the water is in the hands of the villagers of Siloam, who generally drive a hard bargain with their customers during the hot days of autumn.

In the Tyropœon, or central valley, there is a well that supplies water to a Turkish bath. The shaft of the well, 80 feet deep, passes entirely through rubbish, and, at its foot, there is a conduit, cut in the rock, in which the water lies. This conduit has been met with in other parts of the valley, and is in all probabiity connected with the great system of water-works carried out by King Hezekiah. The supply is due partly to infiltration, and partly, perhaps, to the flow of water from a concealed spring higher up the valley; but in either case it passess through the foul mass of rubbish, and acquires a nauseous taste.

Cisterns.—There are four classes of cisterns in the city; first, those which have been made by sinking deep shafts through the rock, and excavating a bottle or retort-shaped collector at the bottom. These cisterns derive their supply in part from the surface drainage of the houses, and in part from the water which finds its way in between the beds of limestone, and they appear to be of very great antiquity. The second class consists of great tanks which have been formed by making small openings in the hard overlying beds of limestone, *missae*, and then excavating the softer *malaki* beneath; they are sometimes from 40 to 60 deep, and have a roof of natural rock, generally strong enough stand by itself, but occasionally supported by rough pillars left for the purpose. The third comprises those in which the rock has been cut perpendicularly downwards, and a plain covering arch thrown over the excavation. These cisterns, as well as those of the second class, were formerly supplied by aqueducts; now they have to depend on surface drainage. The fourth description of

cistern is that which has been built in the rubbish of the city, and is of comparatively modern date. This class is entirely dependent on the rain which falls during the winter.

Reservoirs or Pools.—Amongst the pools in use at present is the *Birket Mamilia*, in the upper portion of the Hinnom ravine, which is so placed as to catch the flood-water during the rainy season; this pool is 315 feet long and 208 feet wide, and holds about eight million gallons, or, allowing for evaporation, six millions; its waters are conveyed by a conduit to the *Pool of Hezekiah*, on the western hill, within the city, which holds about three million gallons. The Birket Mamilla is surrounded on all sides by a large Moslem cemetery, and the Pool of Hezekiah is in very bad repair; its bottom is covered by a thick deposit of vegetable mould, and one corner is nothing more than an open cess-pit of the foulest description; though the water is nominally only used for washing purposes, the poorer classes often draw it for drinking during summer. On the eastern side of the city, immediately without the walls, there is a small pool, called the *Pool of our Lady Mary*, which appears to be of modern date; it holds water after the rains, but is unfavourably situated for collecting the surface drainage. The only remaining pool in use is that of Siloam, which receives the water of the Fountain of the Virgin, already alluded to; it is of comparatively small size.

Aqueducts.—One of the old conduits, that known as the "Low Level Aqueduct," was repaired a few years ago and for a short time delivered water in the city, but it soon got out of order, and I propose noticing it as part of the ancient system of water-works.

You will thus see that the present water supply of Jerusalem is quite inadequate to the wants of the people, and that the quality of the water is very inferior. Those cisterns which have recently been constructed by Europeans, in convents and in dwelling-houses, are carefully cleaned out every year, and keep the water clean and sweet, but such is not the case with the cisterns in the native houses. When the rains commence every duct is opened, and all the summer's accumulation of rubbish is carried through them from courtyard and roof to the cistern below; nor is this all, for even the water from the streets is in many cases allowed to run into the cisterns, bearing with it the foul refuse that has accumulated by the end of the dry season; the streets having been used throughout the year as the common latrine of

the city. The simplest sanitary precautions are neglected, and even in the few instances in which men have been known to clean their cisterns the refuse was only placed in a mass in the courtyard to be washed back again by the first shower. During the early part of summer little evil arises, as the heavier particles fall to the bottom; but, towards autumn, the water gets low, the buckets in descending stir up the deposit, and the mixture which thousands then have to drink as their daily beverage is almost too horrible to think of; at this time, too, a sort of miasma seems to rise up from the refuse, and the fever season commences. In a city like Jerusalem, where there are no statistics, it is difficult to estimate the evils produced by this state of affairs, but I may mention that out of a supposed Jewish population of 9,000 more than 13,000 cases of sickness were attended to during twelve months at their own hospital and that of the Protestant Mission.

Several schemes have been proposed for bringing fresh water into the city, and Lady Burdett Coutts has generously offered to provide the necessary funds, but the local government have hitherto refused to allow any works to be carried out for various absurd reasons which it is unnecessary to enter upon now.

ANCIENT WATER SUPPLY.

So much for the modern supply, but when we look back we find that a large quantity of water was required for the Temple services, and that during the numerous sieges which Jerusalem stood the besieged within the walls never suffered from want of water. So, too, we have evidence in the large pools and cisterns that water was stored in considerable quantities; and there are in the streets the ruins of several beautiful public fountains which, though now used as dust-holes, were as recently as 400 years ago in perfect order and yielding a fair supply of water to the people. The question at once arises, where did this supply come from? and this we have been able to answer with some degree of accuracy, for though we have not been able to unravel all the details, the general scheme is sufficiently clear.

The ancient supply was partly derived from the same sources as the modern one, but the inhabitants appear to have depended chiefly on water brought from a distance by aqueducts, and stored in pools and cisterns. The Fountain of the Virgin, which is probably the Enrogel of the Bible, where Adonijah was holding his feast on the occasion of Solomon's coronation, has already been noticed; but another spring, that of Gihon, is mentioned as having

been stopped by Hezekiah, and its water brought down to the west side of the city of David. This spring appears to have been high up in the central valley; its position has not yet been discovered, but the rock-hewn conduit, which has been found running along the bed of the Tyropœon valley, is believed to be the work of Hezekiah, and the water which finds its way down it is supposed to come from the spring; conduit and spring are now alike buried beneath at least 80 feet of rubbish.

No well has yet been discovered, with the exception of Bir Eyub (Joab's well), which I have previously mentioned, but others may possibly exist beneath the rubbish; near this well, and running beneath the western edge of the bed of the valley, there is a curious work, which must have required a large amount of labour to execute: it consists of a drift or tunnel, some six feet high, two feet to three feet wide, and more than 1,800 feet long, cut in the solid rock, and from 70 to 90 feet beneath the surface; the tunnel is reached by flights of steps at certain intervals, and would seem to have been constructed to catch and collect the water running between the beds of limestone.

In the Temple area we find a large number of cisterns, of what I have called the second and third classes; these were supplied by one of the aqueducts, and were provided with a perfect system of connecting conduits, so that the overflow from one cistern ran into the next, and so on, whilst the final overflow passed into the Kedron valley. One of these cisterns—that mentioned as "the great sea" in the Bible—holds two million gallons, and the total capacity of those in the Temple area is rather more than twelve million gallons. As these cisterns were covered in, and so not exposed to the sun and dry winds, they must always have kept the water cool and pleasant to the taste, and there could have been but slight loss from evaporation.

In addition to the pool Birket Mamilla, near the head of the Hinnom ravine, there is another lower down the same valley, which held about 15 million gallons, but it is at such a low level that the water could only have been used for irrigation or for watering animals. There is also a large pool, the largest in the vicinity of the city, near the head of the Kedron valley, which is admirably situated for collecting the surface drainage of the upper branches of that valley, and lies at a level sufficiently high to supply the Temple area with water; the conduit, however, by which it transmitted its water to the city has not yet been found. Besides the pool of "Our Lady Mary" and the small pool of

Siloam, already alluded to, there was without the walls a second and much larger pool of Siloam, formed by a dam of solid masonry built across the central valley. This pool may once have received the water running down the Tyropœon, "through the midst of the land," from the spring of Gihon, but it is now filled up with rich soil and covered by a luxuriant growth of fig trees. Within the walls of the city there were the Pool of Hezekiah, still in use; the Pool of Bethesda (Birket Israil), which is partly excavated in the rock, and constructed in the bed of the fourth ravine that runs down to the Kedron, north of the Temple area. This pool, in its original form, was only 25 feet deep, but the height of the walls has been increased from time to time, and it is now no less than 80 feet deep, though filled up to a height of 38 feet with rubbish: it holds no water, but receives the drainage of that part of the city. Near the Birket Israil there was another large pool, and there were two others in the city, which have been filled up with soil for many years. All these reservoirs were well constructed, both as regards position and the excellence of the material used.

The most important system of water works was, however, that by which water was brought into the city from the south by aqueducts. The supply was derived from three sources, and the conduits were apparently constructed at different periods; they were of considerable extent, and the remains exhibit a degree of engineering skill which could not well be surpassed at the present day. The first works, and perhaps the oldest, are those connected with the Pools of Solomon. These pools, three in number, are constructed in the bed of a valley not far from Bethlehem, and are so situated that the water from each of the upper pools can be run off into the one immediately below it as the supply is drawn off. The capacity of the pools has been estimated at 44,147,000 gallons, or, allowing for evaporation, 35,265,000 gallons, and they were designed to collect and retain the flood water of the valley during the rainy season. Near the head of the "Upper Pool" there is a spring known as the "Sealed Fountain," which has been estimated to yield 9,720 gallons per diem; and, not far from the "Lower Pool," there is another spring yielding the same quantity, which still retains the name of Ain Etan, or Etham, the place at which Solomon had a summer palace and gardens. These sources, though distinct from the pools, may be estimated with them, as their water was at one time carried to Jerusalem by the same aqueduct, and they would together give, during the ten dry months of the year, a daily

supply of 137,000 gallons. The aqueduct or conduit was very carefully examined by Mr. Macneill, who found that it was 70,000 feet long, and had a total fall of 32 feet, or a mean fall of 1 in 2,187 (less than 2½ feet per mile). It wound round the sides of the hills, passed under Bethlehem through a tunnel, and finally delivered water in the Temple area at Jerusalem. This conduit, which has been called the "low level aqueduct," is that which was temporarily repaired a few years ago, and supplied water to the tanks in the "Noble Sanctuary," as well as to one of the old fountains in the city.

The works connected with the second source of water supply are perhaps the most interesting, on account of the great skill shown in their construction. The conduit has been called "the high level aqueduct," from the fact that it must have delivered water at a level more than 100 feet above that of the "low level aqueduct," and sufficiently high to supply the western hill at Jerusalem. In a valley called Wady Byar, to the south of Solomon's pools, there is a place known as the "well of the steps," where a flight of steps gives access to a subterranean chamber, from 60 to 70 feet below the surface of the valley. From this chamber a well-constructed channel, cut in the rock, leads up the valley for some distance, until it terminates in a natural cleft of the rock: and a similar channel follows the bed of the valley downwards for more than four miles, when it issues from the ground near a solid dam of masonry which extends right across the valley. This great tunnel, to facilitate the construction of which several shafts from 60 to 70 feet deep were sunk in the bed of the valley, was intended to catch the flood-water of the valley, the dam being probably used to retain the water or prevent its running off before it had filtered down to the channel. There are a few small springs in the side valleys which contributed to the supply, but the principal source was the flood-water. About 600 yards below the dam the conduit enters another tunnel, 1,700 feet long, which at one point is 115 feet below the surface of the ground, and, after passing through this, it winds round the hill to the valley in which the pools of Solomon are situated. The conduit crosses the valley above the upper pool, and, tapping the Sealed Fountain, formerly carried its waters onwards to Jerusalem. At first it runs along the side of the Valley of Urtas, but, at a point not far from Bethlehem, it enters a tank, and thence the water was carried over a valley near Rachel's Tomb by means of an inverted syphon. This syphon was about two miles long, and consisted of perforated

blocks of stone set in a mass of rubble masonry some three feet thick all round. The tube is 15 inches in diameter, and the joints, which appear to have been ground or turned, are put together with an extremely hard cement. The whole work is a remarkable specimen of ancient engineering skill, and the labour bestowed on the details excites the admiration of all travellers. On approaching Jerusalem every trace of the conduit is lost; it has evidently been destroyed during one of the many sieges, and the point at which it entered the city is still uncertain. The most interesting feature, however, is that it would have been able to deliver water in the highest part of the city, and so provide an adequate supply for the whole population.

The third source of supply was derived from springs, in a valley called Wady Aroob, one of which was estimated to yield 100,000 gallons a day; as well as from a reservoir or pool in the same valley, about 240 feet long by 160 feet wide. The water from this source was conveyed to the valley in which the Pools of Solomon lie, by a conduit rather more than 30 miles long, which winds round hills and passes through tunnels, or across valleys, by means of a series of well-constructed works. The water at one time reached the Pools of Solomon at a level sufficiently high to be conveyed to Jerusalem by the high level aqueduct and syphon, but it would appear that after these were broken, a small conduit was made to carry the water down to the lower pool, and so enable it to follow the low level aqueduct to the Temple area. This conduit has some interest as being that upon which Pontius Pilate expended the sacred treasure called "corban," an act which greatly incensed the Jews, and finally led to the removal of Pilate from the governorship of Jerusalem.

You will thus see that Jerusalem was, during the brighter period of its history, well supplied with water; and, if we may judge from the number of conduits found during the excavations, the supply was distributed throughout all the quarters of the city.

I will now turn for a few moments to the excavations which have been made at Jerusalem, and endeavour to explain their object and extent. You will remember that I mentioned the eastern hill of Jerusalem as being that on which the Temple stood. Well, on this hill we now find an open, and nearly level space, called the "Noble Sanctuary," which is surrounded by great walls containing some of the most magnificent masonry in the world. Within this enclosure once stood the Temple, but its exact position in the "Noble Sanctuary" has been the subject of much

controversy, and the settlement of this question, which still remains unanswered, was one of the principal objects of the excavations. Of the Temple itself there is no trace, every stone has been removed, and all that we see now is but the shell of the lofty platform on which it stood. The enclosure is looked upon by Moslems as almost equal to Mecca in sanctity, and it was therefore quite impossible to open excavations within the walls. The only alternative was to examine the exterior face of the walls, which were known to be covered to a great depth by rubbish. Experience proved that the amount of *debris* was far greater than anyone had expected, the depths varying from 80 to 125 feet. The only method of examining walls, &c., at these great depths, which could be carried out with any hope of success, was by military mining—that is, by sinking shafts and driving galleries. The shafts were simply square pits, from three to four feet square in the clear, and 50 to 125 feet deep, sheeted with wood to keep the earth from falling in; the sheeting or mining cases were of two to three-inch planks twelve inches wide, each case consisting of four pieces—the two sides with a tenon at each end, and the two end pieces with corresponding mortices. The galleries were tunnels, three feet four inches to three feet eight inches high, and two feet eight inches to two feet ten inches wide, driven out from the side of the shaft, and sheeted with wood in a similar manner. You will thus see that the excavations were no easy matter, and excessively tedious, as, after getting to the bottom of the shaft or end of the gallery, all that could be examined was a small square the size of the opening: nor was the work carried on without some personal risk, for the nature of the rubbish was extremely dangerous. On the rock there was always from two to four feet of rich mould, and above this layers of loose stone chippings, with stones from two to six inches cube, and occasionally great masses weighing several tons: between the layers of chippings there were veins of "fat earth," probably marking the levels of streets at different periods of the city's history, which offered great facilities to the excavators. The great difficulty was to prevent the loose stone chippings, when met with, from running into the galleries and loosening the large blocks, which would then come down with a rush, and crumple up the wooden frames like paper. This, in fact, frequently happened, but fortunately, from the great care with which the work was conducted by Captain Warren, there was no serious accident, though on one occasion a Sergeant of Engineers was shut in for about two hours by a fallen block.

There seems little reason for doubting that the general level of the Temple area was the same as that of the present "Noble Sanctuary," and the excavations showed that at the south-west corner the lowest course of stones in the great enclosing wall was let into the natural rock 110 feet below this level; at the south-east corner 148 feet; and at the north-east corner 155 feet; whilst at the north-west corner the rock rose to the surface. We thus have to the south, east, and west of the level space on which the Temple stood, a wall of solid masonry more than 100 feet in height, and finished in a manner which is rarely seen at the present day. The beds and joints of the stones are chiselled, and the courses are laid without mortar, with such care that the blade of a knife can hardly be inserted between two adjoining stones; whilst the faces of the stones are beautifully dressed, and have a chiselled draft run round their margins. The courses of the stones vary from three feet four inches to four feet in height, and many of the blocks are of great size. The largest hitherto noticed is at the south-west angle, and is 38 feet long, four feet high, and ten feet deep. This block is one of the corner-stones of the wall, and is about 80 feet above the natural level of the ground. The appearance of this solid mass, freed from the rubbish which now conceals more than half its height, must have been grand in the extreme; and as the material, when fresh from the quarry, was a brilliant white, we can scarcely imagine anything more striking or impressive. It may, perhaps, interest you to know that the quarries from which a large proportion of the stone was taken are on the eastern side of the valley which runs through Jerusalem, and at a level almost the same as that of the "Noble Sanctuary." It is believed that the stones were dressed in the quarries, and then run down along the side of the valley, on rollers, to their exact position in the wall; and I may mention that the fourth valley on the east would offer similar facilities for the construction of the eastern wall, as the quarries have an opening into each valley.

Above this great platform rose the temple, surrounded by magnificent cloisters, one of which, on the south side, called the "Royal Cloisters," consisted of a central and two side aisles, each 600 feet long, and the central one 50 feet high; and I may safely assert that no ancient building, or group of buildings, of which we have any record, could compare in grandeur or beauty with those erected by King Herod on Mount Moriah. Nor were the approaches neglected. On the southern side the wall was

pierced by two fine gateways, approached from without by a flight of steps, or ramp, and communicating on the inside with a vestibule, which still retains traces of its former beauty in a large monolith, and some elaborate carving on the stone roof. From this chamber there was a gradual ascent by two covered passages to the temple courts.

On the west there were, as Josephus informs us, four approaches to the Temple; and on these the excavations of Captain Warren have thrown much light. One is said to have led down from the Temple to the Tyropœon Valley by a flight of steps, and then to have ascended the western hill; another to have crossed the valley, and led to Herod's palace; and the two remaining ones to have communicated with the suburbs, which were apparently in the Tyropœon. Near the south-western corner of the wall there are the springing-stones of a large arch, known as "Robinson's Arch," and on excavating near it the foundations of the pier and the fallen voussoirs were found amongst the rubbish far below the present surface of the ground. The span of the arch was forty-one feet six inches, and its breadth fifty feet, which exactly corresponds with the width given by Josephus to the central aisle of the "Royal Cloisters;" so that there is no doubt this entrance passed into the grand colonnade south of the Temple. It is supposed that a broad flight of steps led down from the arch to the valley; but no traces of the remaining piers or of the supporting arches have yet been discovered. The appearance of this arch, spanning the narrowest part of the ravine at a height of 70 feet above the ground, must have been extremely effective.

The next approach, that which led across the valley from Herod's palace to the Temple, was in the form of a roadway supported on a series of arches, the largest of which abutting on the Temple wall was found by myself and has been named "Wilson's Arch." It has the same span as "Robinson's Arch," and seems to have been of similar construction. Some of the remaining arches were found by Captain Warren, but the lower ones at the western end have been broken and lost. A glance at the map will at once show why one approach ascended to the Temple by steps, and the other passed over arches. Opposite the southern arch the western hill is much higher than Moriah, and any approach carried on a series of arches would have descended to the Temple, and so taken away from its apparent elevation, whereas the ascent by steps rather added to this effect. Opposite the northern arch, on the contrary, a small tributary to which I have already alluded fell into the Tyropœon valley from the west, and the roadway, or

viaduct, after crossing the Tyropœon on a level, passed up this valley to Herod's palace.

Of the posterns which led to the suburbs, one—known as "Barclay's Gate," from its discoverer—was between Wilson's and Robinson's arches, and several portions still remain. The doorway is 28ft. 9in. high, and its sill is 49ft. 9in. above the natural rock; it was approached from the valley by a ramp, or mass of sloped earth, and from it a vaulted passage led perpendicularly inwards for 69 feet, to a fine domed chamber: here the passage turned at right angles to the south, and ascended gradually to the surface, which it reached in the central aisle of the "Royal Cloisters." The remaining postern was found by myself, to the north of Wilson's arch, but the number of buildings in its vicinity has prevented all excavation, and we merely know of its existence.

Much has been done by excavation towards elucidating the general character of the masonry platform on which the Temple stood, but the site of that building is still uncertain. Josephus gives a somewhat minute account of the Temple and its surrounding courts and cloisters, but he was writing for people who had seen the Temple in all its glory, and were well acquainted with its details. He gives no indication of the exact position of any one particular point, and we are thus to a certain extent working in the dark. Could we obtain a clue to his description, the mystery would soon be solved; but that clue, though I have no doubt it will hereafter be discovered, is still wanting, and until it is found we must content ourselves with knowing what the general character of the buildings was.

And now, in conclusion, I would endeavour to enable you to realise what sort of a place this Temple was before it was destroyed by the Romans during the great seige of Jerusalem by Titus, and I cannot do this better than in the words of Mr. Fergusson, the well known architect: "In order to try and realise the whole, fancy a building like the nave of Lincoln, raised on a lofty terrace, and standing in a court surrounded by cloisters and porches. Fancy these courts approached by ten great gateways, each in itself a work of great magnificence; and again this group surrounded by another court on a lower level, one side of which is occupied by a building longer and higher than York Cathedral, and the other three sides by cloisters more magnificent than any we know of; and all this supported by terrace walls of such magnificence of masonry, that even at this day, in their ruined state, they affect the traveller as much, perhaps, as any building of the ancient world."